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MODEL PERFORMANCE EVALUATION OF THE US EPA INDUSTRIAL SOURCE COMPLEX (ISC) AND THE 0.55 ADJUSTED MODEL

Science and Technology Branch
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1.0 INTRODUCTION

1.1 Background

In January 1998, a month after Alberta Environmental Protection (AEP) released the latest draft of the Air Quality Model Guidelines (AQMG), a one-day workshop was held at which stakeholders were invited to provide feedback on the guidelines. As a result of that workshop a "Model Modification Task Group" was formed to address the issue of the "0.55 correction factor". The group of volunteers, comprised of consultants, industry, the Energy Utilities Board (EUB) and AEP, set out to resolve the issue of whether or not AEP should incorporate the 0.55 correction factor for the Industrial Source Complex version 3 (ISC3) model into the guidelines.

During their discussion, the Model Modification Task Group looked at the background science behind the "0.55 factor" and considered alternatives, including the use of the High nth High concentrations from the ISC3 model. While the group did not reach consensus on the issue, it did offer a number of recommendations for possible solutions. In response to the recommendation report, AEP decided to carry out a model performance evaluation so that a decision could be made as to which version of the ISC3 model would be implemented in the guidelines.

Ultimately, the project will incorporate modelling of ISC3, 0.55 ISC3, AERMOD and CALPUFF, to determine which models are appropriate for recommendation into the AQMG. This report presents the results of the first stage of the project, which compares the US EPA ISC3 and 0.55 ISC3 models.

1.2 Objectives

The main objective of this paper is to determine which version of the ISC3 model (US EPA or 0.55) performs better and to select one model for regulatory purposes. The paper focuses on the 1-hour averaging period for two reasons. Firstly, because the maximum 1-hour predictions from the models have the greatest regulatory consequence, and secondly because the 0.55 factor has the greatest effect on a 1-hour predicted concentration compared with longer averaging times of the 24-hour or annual periods. This paper also touches on other topics related to the modelling, such as predicting extreme values, emissions parameterisation, and the High nth High.

2.0 METHODOLOGY

2.1 Overview

The model performance study was designed to cover a number of different scenarios over a wide array of sources and topography. The modelling focused in on one main pollutant, SO_2, to keep comparisons among study areas consistent. SO_2 was selected for a number of reasons:

- It is one of the most widely emitted pollutants in Alberta.
- There is a significant amount of emissions data and ambient monitoring for SO_2.
- Final model selection will most likely have the greatest impact on SO_2 management.

Several criteria were considered when selecting sites to use in the study:

- The study areas had to have point sources of SO_2 with well-documented emission data because the 0.55 factor only applies to point sources.
- Monitoring data had to be available for simple terrain (terrain below stack top) because the 0.55 factor only applies to simple terrain.
- At least two monitors, with six months of monitoring data had to be available.
- Meteorological data that represented the source location had to be available for the coinciding time period.

The number of monitors in each study area varied, as did the time period of study. Model predictions were made for each monitoring location at times when corresponding monitoring, meteorological, and where possible, emissions data were available. For each scenario predictions of the regular and 0.55 ISC3 model were then compared with the measured SO_2 concentrations at each monitor using various statistical methods.

2.2 Case Studies

Four locations were found to be suitable. The amount of data that was available for these sites helped to ensure that a comprehensive comparison could be performed. The models were run for the following locations in Alberta:

- Fort Saskatchewan
- Balzac
- Waterton
- Oil Sands region north of Fort McMurray

A total of twenty-three monitoring stations are located in the proximity of the sources; eighteen were suitable for the study (Table 2.1). Five of the Oil Sands monitors are situated in what could be classified as complex terrain. Therefore they are not suitable for this comparison.

Table 2.1: Locations of the Monitoring Trailers

Plant Name	Monitor Name	UTME (m)	UTMN (m)	Elevation (m)	Distance from Main Source to Montior (m)	Direction to Monitor (m)
Fort Saskatchewan	Shell Trailer	361895	5963375	624	n/a	n/a
	Redwater Disposal #8-1	360600	5983750	610	n/a	n/a
	Redwater Disposal #14-36	369125	5972825	602	n/a	n/a
	Imperial Trailer	363775	5978625	617	n/a	n/a
Balzac	Trailer No. 2	297302	5678227	1107	4250	NE
	Trailer No. 3	297110	5673372	1099	3150	SE
Waterton	Bonertz Trailer	291477	5463845	1337	8900	NE
	Carpentier Trailer	291477	5463845	1350	9750	SE
	McRae Trailer	291692	5469505	1333	10300	NE
	Riviere Trailer	284246	5466551	1480	2100	NE
	Burns Trailer	288257	5470250	1345	7550	NE
Oilsands	Lower Camp	469300	6320800	245	*6900	E
	Poplar Creek	472400	6306000	245	*19400	SE
	Athabasca Bridge	464200	6333000	260	*11300	S
	AQS4	461100	6334200	265	*12400	N
	AQS5	462500	6329500	278	*7000	N
	Fort McMurray	476100	6287300	254	*42900	SSE
	Fort McKay	461800	6337400	244	*16000	N

*** Suncor Main Stack**

Each location is characterised by its own unique set of circumstances; the following sections describe each study area separately.

2.2.1 Fort Saskatchewan

Fort Saskatchewan is located near an urban area, with many sources of SO_2 concentrated into a relatively small region. A topographic map of the area (Appendix A, Figure A1) shows that the terrain surrounding the site is relatively flat. The four monitors used in the study (Redwater Disposal Trailers #14-36 and #8-1, Shell Trailer and the Imperial Trailer) are all located between Fort Saskatchewan and Redwater in relatively flat terrain near the sources' elevations.

The modelling methodology included the available historical emission rates for all sources of SO_2. This method is consistent with the modelling that was done for the recent Shell Scotford EIA[1]. Wind and temperature data were taken from Shell Canada Limited's Scotford Refinery monitor and used in combination with Namao Airport cloud data to determine frequencies of atmospheric stability according to the Pasquill (1961) method. Mixing heights were calculated according to Benkley and Schulman's (1979) method using upper air data from Environment Canada's Stony Plain upper air station.[2]

[1] Shell Canada's Supplemental Information for the Scotford Upgrader Project, 1998, pg. 46
[2] Shell Canada's Environmental Impact Assessment for the Proposed Scotford Upgrader, 1998, pg. B1-15

2.2.2 Balzac

Balzac is located directly north of Calgary in close proximity to the city. A topographic map (Appendix A, Figure A2) shows the flat terrain surrounding the site. The two monitors found in the region (Trailer 2 and Trailer 3) are of similar elevation to the main source of SO_2.

For the Balzac study area an average emission rate that corresponded to the available ambient monitoring was used. Surface data from the Calgary International Airport and upper air data from the Stony Plain Upper Air Station provided the meteorological data that was the most representative of the site. Stabilities and mixing heights were determined in a similar fashion to those used in the Fort Saskatchewan region, by Pasquill (1961) and Benkley and Schulman's (1979) methods respectively.

2.2.3 Waterton

The Waterton study region is a rural area occupying the southwest corner of Alberta, with British Columbia's border just to the west and the United States to the south. A topographic map (Appendix A, Figure A3) shows that the terrain surrounding the site is relatively flat to the east becoming much more complex to the south and west. Although this is an area of complex terrain, all of the monitors are located at or below stack base. The Riviere, Burns, McRae, Bonertz and Carpentier Trailers vary in distance and with elevation.

For Waterton modelling, sequential on-site emission rates, meteorology and monitoring for one year were available. Most of the meteorological parameters were available from an on-site station. The other necessary parameters were taken from the nearby AES Pincher Creek station. This station is located approximately 36 km north of the site in similar topography. The twice-daily mixing heights were generated from the surface and Stony Plain upper air data using the Holzworth method (A Mixing Height Study for North America (1987-1991), Senes Consultants Limited, 1996). The twice-daily mixing heights along with the surface data were then processed by interpolation in order to generate stability classes and mixing heights on an hourly basis.

2.2.4 Oil Sands

The area referred to as the "Oil Sands" is located in Northeastern Alberta close to the communities of Fort McKay and Fort McMurray. A topographic map (Appendix A, Figure A4) shows the region. Although there are twelve monitors located in the area, only seven of those are situated in simple terrain relative to the sources (Lower Camp, Poplar Creek, Athabasca Bridge, AQS4, AQS5, Fort McMurray, and Fort McKay). Thus only these stations were utilised for comparison.

Modelling for the Oil Sands portion of the study followed the same methodology as the historical modelling (EIA) of the 1998 Suncor Project Millennium Application[3]. Meteorological data was used from the 75m level of the Mannix station. The Mannix data was used to determine both mechanical and convective mixing heights; the larger of the two for each hour was then used in the model.[4]

2.3 Data Analyses

Once the model runs were complete the predicted concentrations were compared to the ambient monitoring concentrations using three different approaches. First results were tabulated, and predicted versus observed data were directly compared.

Many mathematical operations could be performed on the results, but the dimensionless Mean Square Error (M) performance measure was selected as a primary indicator of performance. This was done because the resultant single number provides an easy comparison of the two models. If C_o is the observed concentration, and C_{pi} is the predicted concentration from model i. M is calculated according to equation (1):

$$M=\overline{(C_{pi}-C_o)^2}/(\bar{C}_o\bar{C}_p) \qquad (1)$$

where the bars are the averages. This method places a higher weight on the extreme values, because the difference in the observed and predicted concentrations (C_{pi}-C_o) is normally the highest at highest concentrations. The lower the value of M, the better the model has performed. Because the interest in this paper is on the highest values, M was calculated over the top ten observed and predicted values.

The second comparison involved computing cumulative frequencies of predicted and observed concentrations for each monitoring location. This is a useful tool as it provides a visual comparison between each version of the model and the observed results on an overall basis. The cumulative frequency compares data for the entire time period of study as opposed to the fractional bias, which compares only the top twenty-five concentrations. When viewing the graphs one should pay attention to how well the plotted line representing the model corresponds with the line representing observed concentrations. The closer the lines are the better the model corresponds to the observed values. It should also be noted how the two versions predicted on the extreme values (>99.9%).

The final form of analysis involved calculation of an overall fractional bias of the models at each of the monitoring locations. The fractional bias (FB) is a performance measure

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[3] Suncor's Project Millenium Environmental Impact Assessment, Appendix III, Air Quality Modelling Documentation

[4] Technical Reference for the Meteorology, Emissions and Ambient Air Quality in the Athabasca Oil Sands Region, Golder Associates Ltd. and Conor Pacific Environmental Technologies Inc. for Suncor Energy Inc., Oil Sands, 1998, pgs.26, 34-37

used to determine if a model meets the minimum standards for operational performance.[5] It is calculated according to equation (2):

$$FB = 2\frac{(OB-PR)}{(OB+PR)} \qquad (2)$$

The fractional bias is calculated twice for each monitoring station. The first time using average values, where OB and PR are equal to the averages of the top twenty-five observed and predicted values, and the second time using standard deviation, where OB is the standard deviation of the highest twenty-five observed values, and PR is the standard deviation of the highest twenty-five predicted values. The resulting two values are then plotted with bias of average on the x-axis and bias of standard deviation on the y-axis. When used as a screening tool the range of bias should be between –2.0 (extreme overprediction) and +2.0 (extreme underprediction) as a minimum in model performance. The closer the fractional bias is to the centre of the plot, the fewer tendencies it has towards any bias. The US EPA recommends using the +/- 0.67 point where the fractional bias either overpredicts (-0.67) or underpredicts (+0.67) by a factor of two. The Protocol for Determining the Best Performing Model recommends that the bias be computed for a number of meteorological scenarios and conditions. However, in many circumstances there is insufficient data to fully carry out appropriate analyses.

3.0 MODEL RESULTS

3.1 Direct Comparison

Table 3.1 shows direct comparisons of maximum 1-hour concentrations (predicted and observed) for each monitor. A summary of table 3.1 shows that the maximum predicted 1-hour concentrations of the regular US EPA ISC3 model over predicted at nine of the eighteen monitors while the 0.55 model over predicted at only three of the eighteen monitors.

Table 3.2 shows the dimensionless Mean Square Errors for both models at each monitor location. The difference between each mean square is given to illustrate how each model performed. A negative value indicates that ISC3 performed better, where for a positive value, 0.55 ISC3 performed better.

According to this analysis, the ISC3 performed better at twelve of the eighteen monitors. The overall average M of all the monitors was 0.341 for the ISC3 model, and 0.489 for the 0.55 ISC3. This value shows that the ISC3 model had a better overall performance.

[5] Protocol for Determining the Best Performing Model. U.S. E.P.A., December 1992, pg. 4-8

Table 3.1: Maximum 1-Hour Concentrations for each Monitor, Predicted and Observed

Plant	Monitor	Maximum 1-Hour Concentration				
		ISC3 ($\mu g/m^3$)		0.55 ISC3 ($\mu g/m^3$)		Observed ($\mu g/m^3$)
Fort Saskatchewan	Shell Scotford Trailer	343	O	238	O	184
	Redwater Disposal #8-1	475	U	359	U	648
	Redwater Disposal #14-36	273	U	219	U	509
	Imperial Trailer	444	O	310	U	407
Balzac	Trailer 2	94	U	52	U	105
	Trailer 3	105	U	59	U	157
Waterton	Bonertz	238	O	132	U	197
	Carpentier	306	O	177	O	83
	McRae	178	U	129	U	216
	Riviere	189	U	107	U	260
	Burns	231	O	135	U	193
Oil Sands	Lower Camp	539	U	328	U	1490
	Poplar Creek	307	U	182	U	388
	Athabasca Bridge	523	O	313	U	445
	AQS4	517	U	338	U	720
	AQS5	669	O	409	U	581
	Fort McMurray	555	O	315	O	254
	Fort McKay	493	O	273	U	390

*** (Overpredictions denoted by "O" and Underpredictions by "U")**

Table 3.2 Calculated Mean Square Error at Each Monitor for both Models

Location	MONITOR NAME	ISC3 MSE (M1)	0.55 ISC3 MSE (M2)	Difference (M1-M2)	Best Performing Model
Fort Saskatchewan	Shell Scotford Trailer	0.580	0.150	0.430	0.55
	Redwater Disposal Trailer #8-1	0.411	0.607	-0.196	ISC3
	Redwater Disposal Trailer #14-36	0.018	0.113	-0.095	ISC3
	Imperial Trailer	0.124	0.018	0.106	0.55
Balzac	Trailer No. 2	0.126	0.214	-0.088	ISC3
	Trailer No. 3	0.085	0.696	-0.611	ISC3
Waterton	Bonertz Trailer	0.020	0.349	-0.329	ISC3
	Carpentier Trailer	1.080	0.260	0.820	0.55
	McRae Trailer	0.080	0.480	-0.400	ISC3
	Riviere Trailer	2.040	3.380	-1.340	ISC3
	Burns Trailer	0.316	0.101	0.215	0.55
Oilsands	Lower Camp	0.430	1.260	-0.830	ISC3
	Poplar Creek	0.020	0.390	-0.370	ISC3
	Athabaska Bridge	0.008	0.218	-0.210	ISC3
	AQS4	0.059	0.242	-0.183	ISC3
	AQS5	0.197	0.037	0.160	0.55
	Fort McMurray	0.523	0.047	0.476	0.55
	Fort McKay	0.015	0.241	-0.226	ISC3
Average	Average	0.341	0.489	-0.148	ISC3

Table 3.3: Highest 1st through 6th – 1-Hour Concentrations for Each Monitor as Predicted by the US EPA ISC3 Model

Plant	Monitor	Highest 1-hour Concentrations (µg/m^3)					
		First	Second	Third	Fourth	Fifth	Sixth
Fort Saskatchewan	Shell Scotford Trailer	343	343	341	341	341	339
	Redwater Disposal #8-1	475	472	455	431	417	407
	Redwater Disposal #14-36	273	248	246	228	218	218
	Imperial Trailer	449	439	388	385	381	377
Balzac	Trailer 2	94	93	88	87	82	79
	Trailer 3	105	94	72	69	68	68
Waterton	Bonertz	238	171	139	130	116	111
	Carpentier	306	214	118	111	105	103
	McRae	178	155	145	127	127	120
	Riviere	189	139	56	49	45	40
	Burns	231	201	177	148	135	134
Oil Sands	Lower Camp	539	520	453	448	447	440
	Poplar Creek	307	302	287	286	272	257
	Athabasca Bridge	523	431	425	390	387	385
	AQS4	517	484	454	448	420	376
	AQS5	669	548	531	507	502	470
	Fort McMurray	555	499	474	436	378	342
	Fort McKay	493	355	322	301	294	288

Tale 3.3 outlines the highest 1st through 6th concentrations as predicted by US EPA ISC3 model at each monitor. The results show that the 1st through 6th high concentration varies from site to site. In some instances the concentration drops off rapidly from the maximum (e.g. Athabasca Bridge, Fort McKay) while in others, even the sixth highest concentration was similar to the highest concentration (e.g. Shell Trailer, Trailer 2, Poplar Creek). This variance in results makes it very difficult to choose a level that is consistent with monitors, or with the 0.55 ISC3 model.

3.2 Cumulative Frequencies

A cumulative frequency chart was created for predicted and observed concentrations at each of the eighteen monitors (Appendix B, Figure B1-B18). The charts show the percentage of concentrations that will be below a certain level. When the observations and predictions match up, the model is predicting well. This is a convenient way of comparing observations and predictions without matching them temporally.

Most of the charts do not show the lower frequencies. This was done for a couple reasons. Most of the time, both the model and the observations will not be predicting or observing a concentration therefore, having a cumulative frequency of zero for those periods. Second, the monitors only register concentrations that are 0.01ppm(approx. 20µg/m^3) or greater, while models can make predictions for any value greater than 0ppm(µg/m^3). Therefore, a certain amount of error could be introduced on the lower end of the scale. The main interest here lies in the extreme values.

Also, at times on the lower percentages, the 0.55 frequencies may be slightly greater than the regular ISC3 model. The Imperial Oil cumulative frequency chart (Figure B4 in Appendix B) best illustrates the reason for this. Due to the wider plume of the 0.55ISC3, the 0.55 model may "hit" a receptor when the ISC3 model does not, causing a greater frequency of concentrations from the 0.55 ISC3 on the lower end.

The cumulative frequencies are discussed for each study area as follows:

3.2.1 Fort Saskatchewan

Because the Fort Saskatchewan modelling was done using historical emission rates for all sources, it is expected that the predicted values would agree with the observations in most instances.

As expected the Redwater Monitors (Figures B2 and B3) corresponded to observed values well on an overall basis for both models. The observations at the extreme prediction were much higher ($M_{ISC3,0.55}$>0.4 for Redwater #8-1), which could be a result of an upset condition that is captured in the modelling. This was not the case however, with the Shell and Imperial Oil Monitors (Figures B1 and B4), where both models over predicted by a significant amount.

3.2.2 Balzac

Balzac modelling utilized a one-year average emission rate that corresponded to the monitoring data. No upset conditions occurred during periods where the monitors were recording concentrations. Using the average emission rate represents more realistic conditions; therefore, it is expected that the results would be much more comparable to the observations, with perhaps some instances of under prediction.

Both Trailers (Figures B5 and B6) correlated quite well with observed values. At the extreme values (>99.8%) the ISC3 resulted in a slight over prediction, while the 0.55 under predicted. Regulatory modelling currently requires the maximum one-hour emission rate to be modelled. However, the results show that the average emission rate matches better with the observed monitoring data, than a maximum emission rate would. The average emission rate also captured the extreme maximum concentrations for the time period. Thus utilising a maximum emission rate would be overly conservative, unless the facility was to run at that rate constantly.

3.2.3 Waterton

Waterton modelling used sequential emissions, meteorology, and monitoring data in an attempt to incorporate as much realism into the two models as possible. Because of the detail, this method was expected to yield the most accurate predictions. However the models did not predict as well as expected. This may have happened for a couple of reasons:

- The facility is located in complex terrain. Chinook winds can dominate the area from time to time, pulling the plumes down the slopes (where the monitors are located) causing higher concentrations. The models do not address this type of process well.
- The emission rates at the Waterton facility can vary by as much as 4.7 Tonnes/hour. Although most upset conditions were incorporated. The chance of successfully capturing the correct meteorology during periods when emissions are higher is quite low.

Nonetheless, the predictions were good ($M_{ISC3}<0.1$ at two monitors), although under prediction was prevalent (Figures B7 to B11). The charts show frequencies above the 98th percentile. The Riviere Monitor (closest to source) performed very poorly ($M_{ISC3}=2.04, M_{0.55}=3.38$); most likely due to upset times that were not "captured" in the meteorology. Further analysis into these results may be necessary. At the extreme levels, the US EPA ISC3 tended to follow the trend of the observed values better than the 0.55 ISC3.

3.2.4 Oil Sands

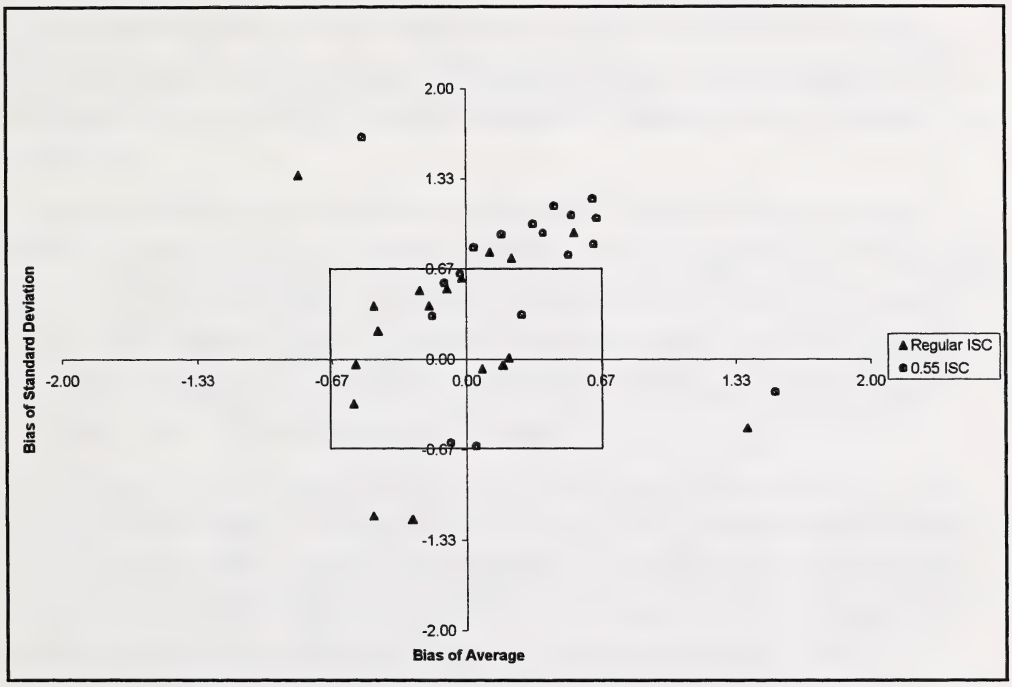
Extensive modelling has previously been completed for this region. The emission parameters utilised best fit the historical data for the time period of the monitoring. The charts (Figures B12 to B18) show excellent correlation with observed values, including the top ten values where M was between 0.008 and 0.5 in all cases except for the 0.55 model comparison for the Lower Camp monitor. In some instances, the ISC3 over predicted slightly at the extreme values, but on the whole ISC3 extreme predictions were much closer to the observed maxima than the 0.55 ISC3. This study area had the best overall predictions compared with the other studies.

3.3 Fractional Bias

The fractional bias for both the US EPA and 0.55 versions of the ISC3 model were determined for each monitoring station. The results were plotted together on one graph (Figure 3.1) to give an overall comparison of the two models' performance at all locations. The area of the graph with a fractional bias within 0.67 has been outlined for convenience. As stated in the methodology, this value may be used as an indicator that a model plotted within the guideline is overpredicting or underpredicting within a reasonable limit.

Each triangle represents a monitor where the ISC3 is compared with observed values. Each circle represents a monitor where the 0.55 ISC3 model is compared with observed values.

Figure 3.1: Fractional Bias for the 1-hour Averaging Period



The fractional bias shows that the US EPA ISC3 model has eleven of the eighteen monitors within the acceptable limits while the 0.55 version has only six of eighteen monitors within the acceptable limits. It is important to note that all of the monitors that performed well among fractional bias, the Mean Square Error and over- or under-prediction comparison are different in each analysis.

The regular ISC3 has many points located to the left of the y-axis indicating a tendency towards overprediction; this is shown in the top twenty-five observations. The 0.55 model on the other hand does over predict in some cases but more consistently under predicts. The plot shows that the 0.55 ISC3 model has a positive bias of standard deviation greater than 0.67 in most instances. This means that the observed top twenty-five values of many of the monitors did not exhibit a similar variance in concentrations to the 0.55 ISC3 predicted values; observed values were more like the ISC3 predicted values.

If maximum emission rates were modelled, the bias would move in a Southwest direction (if the top of the page were North). This may improve the results of the 0.55 ISC3. It is important to note that the modelling scenarios represent more "realistic" conditions at

each site. Therefore, the model that performs best under these conditions is the better model. The results of the 0.55 model may improve with maximum emissions, but it would be for the wrong reason.

4.0 CONCLUSIONS

The US EPA ISC3 and 0.55 ISC3 models were evaluated for their ability to predict concentrations of SO_2 for a 1-hour averaging period. Observed ambient air monitoring data and each model's corresponding predictions at eighteen monitoring locations were evaluated by means of direct comparison, cumulative frequency plots and fractional bias calculations.

According to the results of the study the US EPA ISC3 model was found to perform better. The unmodified ISC3 model over predicted at ten of the eighteen monitors used in the study while the 0.55 model overpredicted at three of the eighteen monitors. The Mean Square Error showed the ISC3 model performed better on the top ten concentrations at twelve of the eighteen monitors. Fractional bias analyses rated eleven of the eighteen monitors run with the US EPA model as being within acceptable limits, and only six of the eighteen with the 0.55 model. This supports the conclusion that the ISC3 model, unadjusted, should be preferred to the 0.55 model.

The regulatory use of the High nth High concentration from the ISC3 model was also addressed in this paper. By comparing the 1st through 6th high concentrations predicted by ISC3 at each monitor, a great deal of variability in the distribution of predicted and observed values among the different monitors was noted. There would be no degree of confidence in selecting a High nth high level, as the distribution of concentrations for each point would not sufficiently be stabilised or consistent from case to case. Considering that emissions data vary over time, then so too would the maximum concentrations. Selecting a high nth high value would only be based on the model's limited ability to predict extreme values and not based on which value best corresponds to results.

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APPENDIX A

Figure A1: Map showing location of Monitoring Stations in relation to Redwater and Fort Saskatchewan

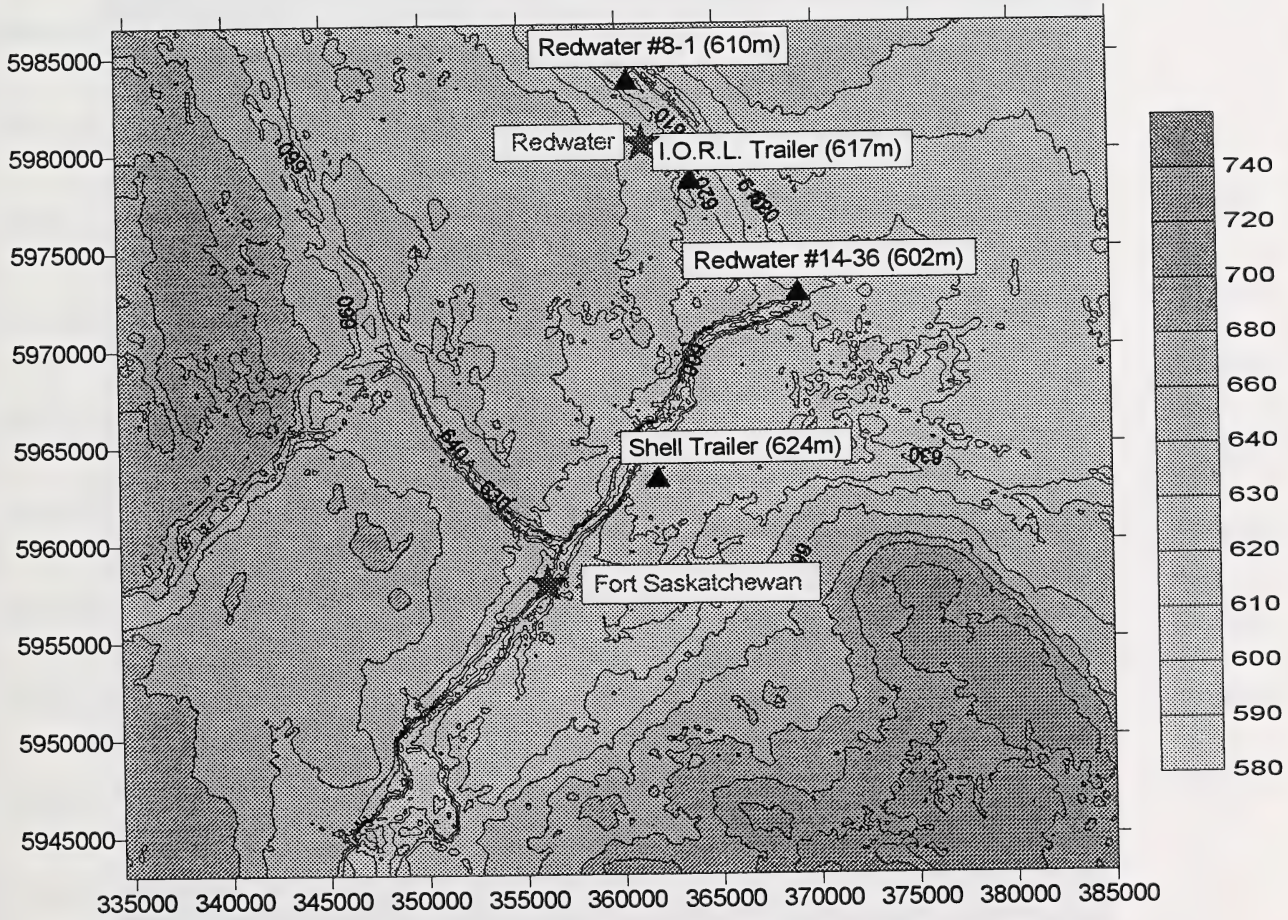


Figure A2 Map showing location of the Balzac Plant Incinerator and Monitoring Stations (contour interval 20m)

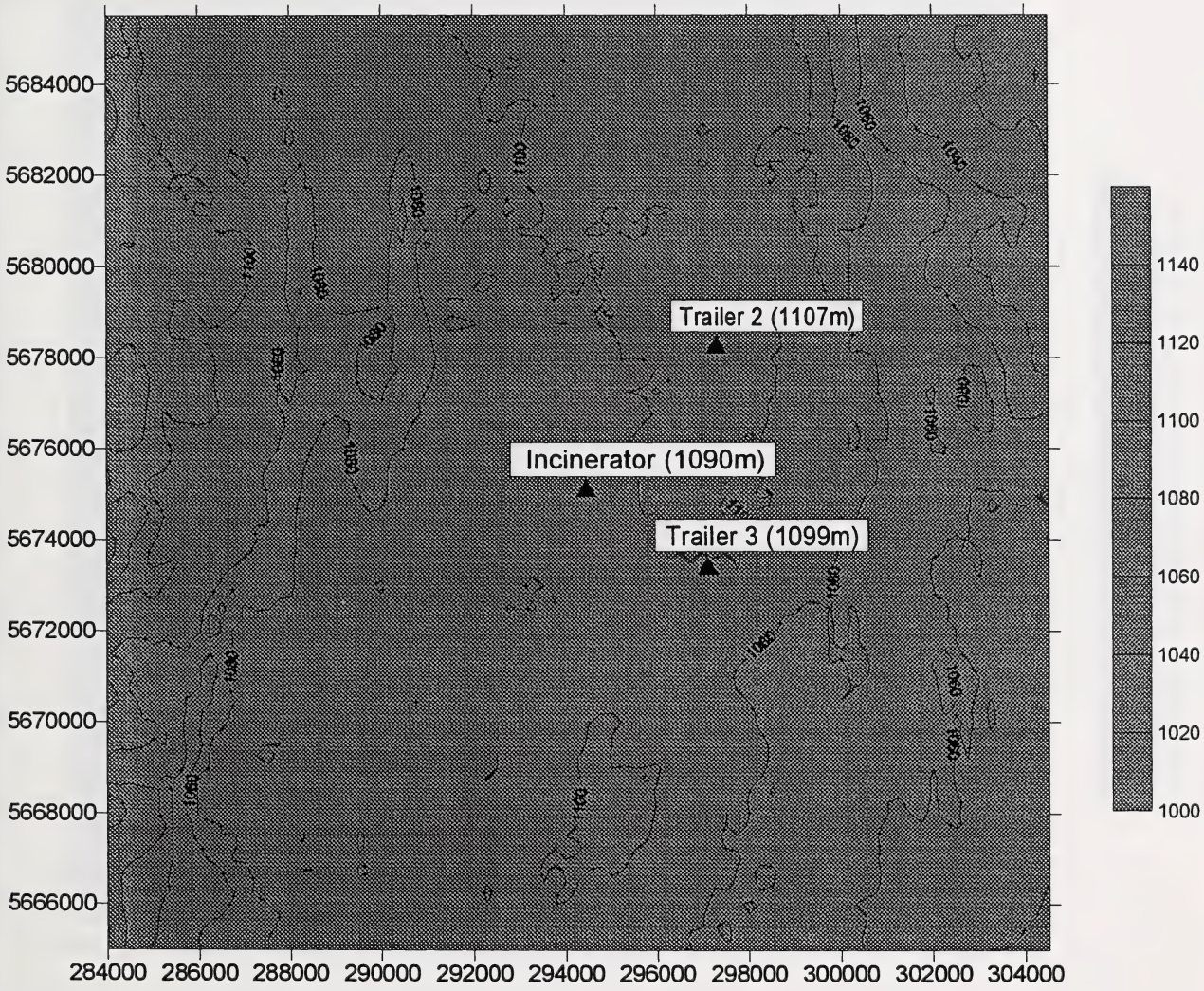


Figure A3: Map showing location of Waterton Plant Incinerator and Monitoring Stations

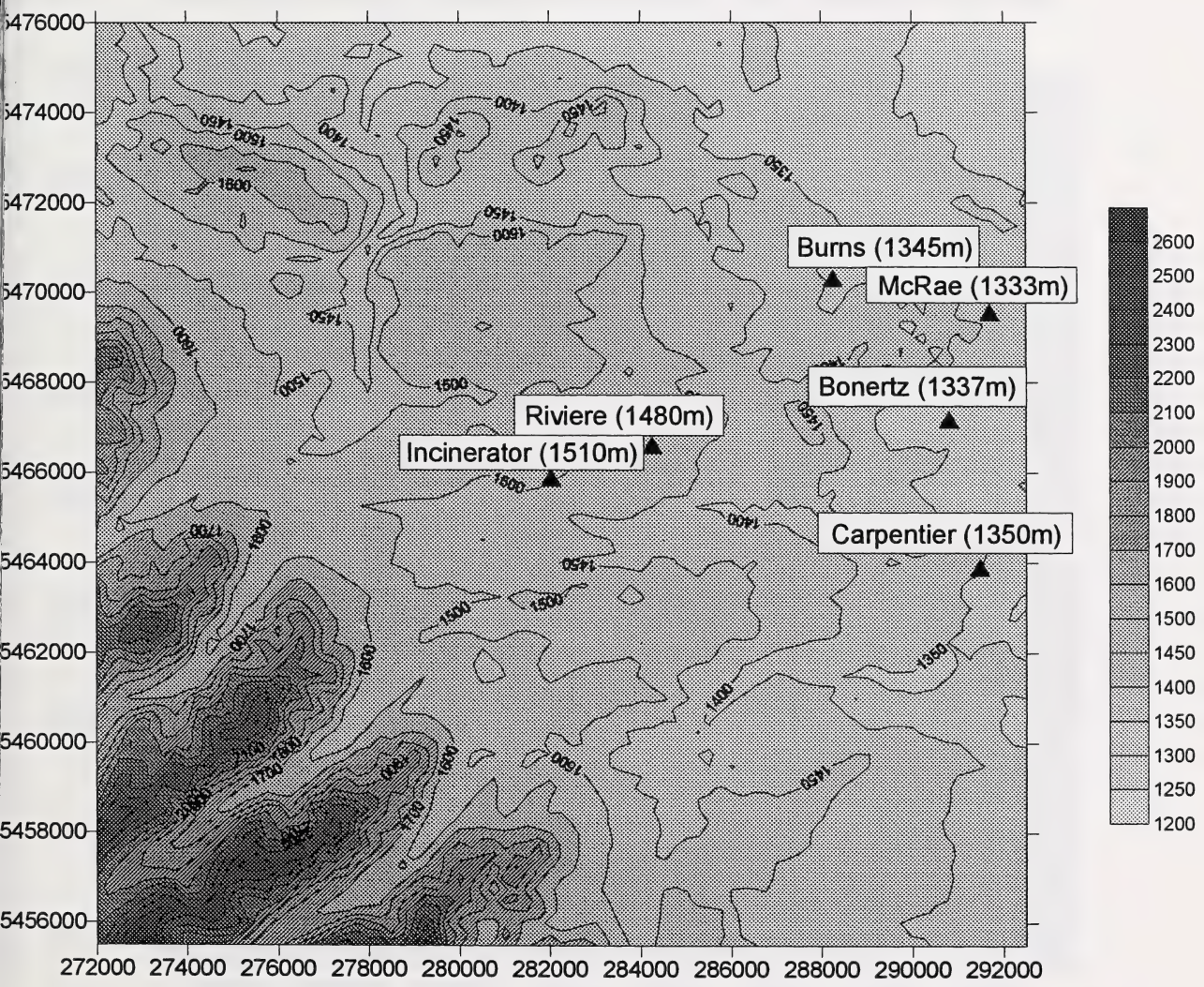
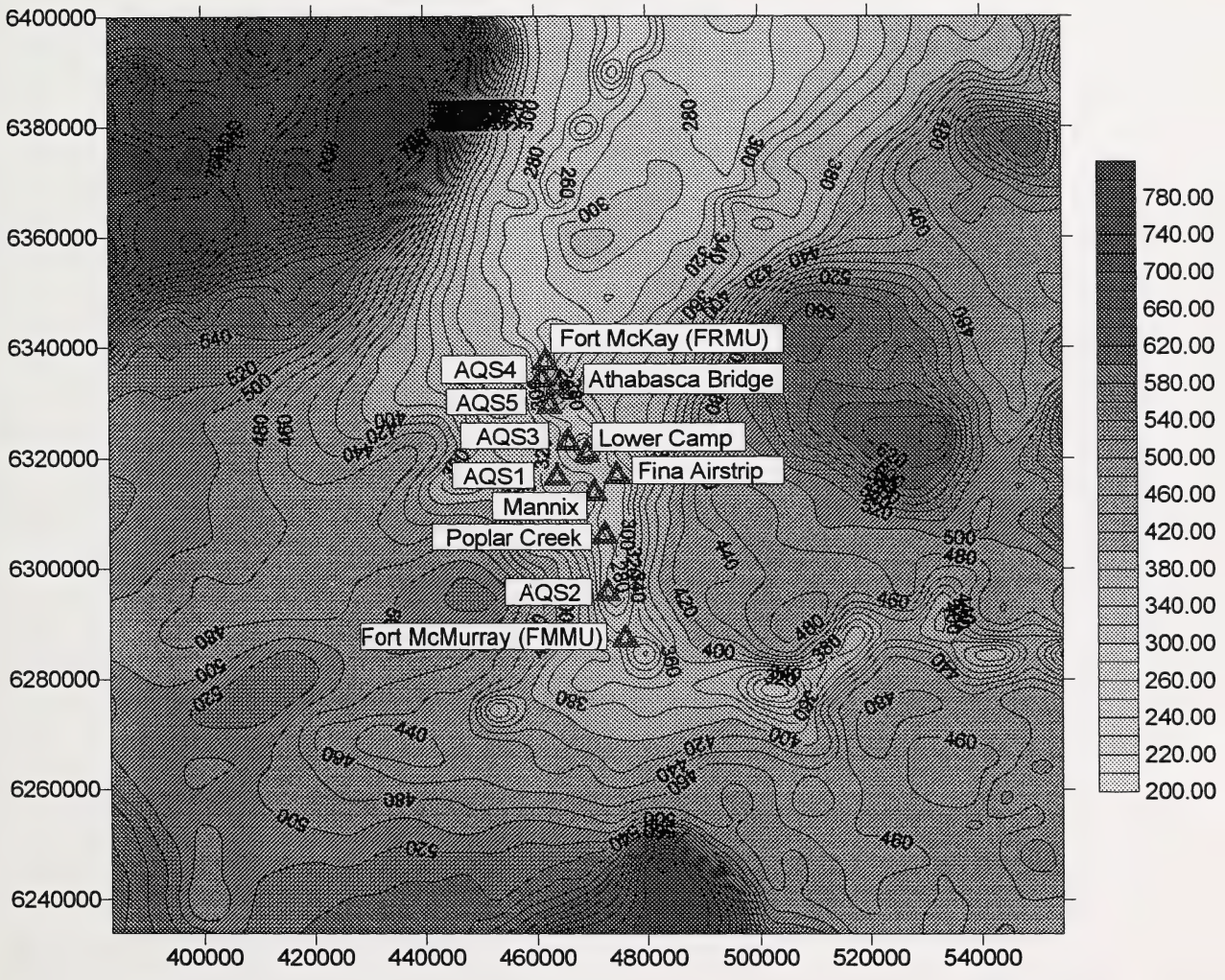


Figure A4: Map showing location of Monitoring Stations in the Oil Sands area



APPENDIX B

Figure B1: Cumulative Frequency of Predictions and Observations for the Shell Monitor 1993-96, Fort Saskatchewan

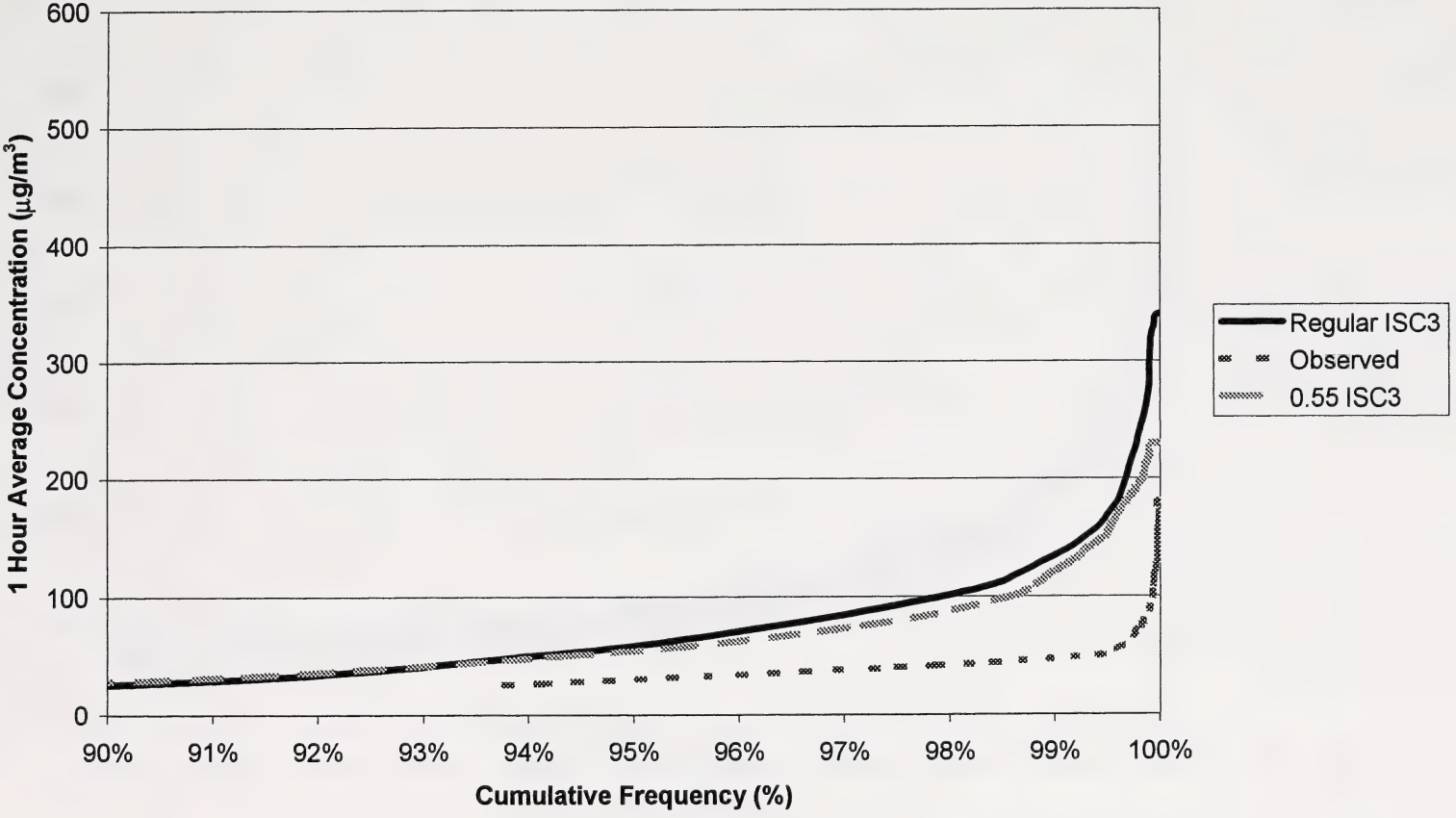


Figure B2: Cumulative Frequency of Predictions and Observations for the Redwater Trailer #8-1, Fort Saskatchewan

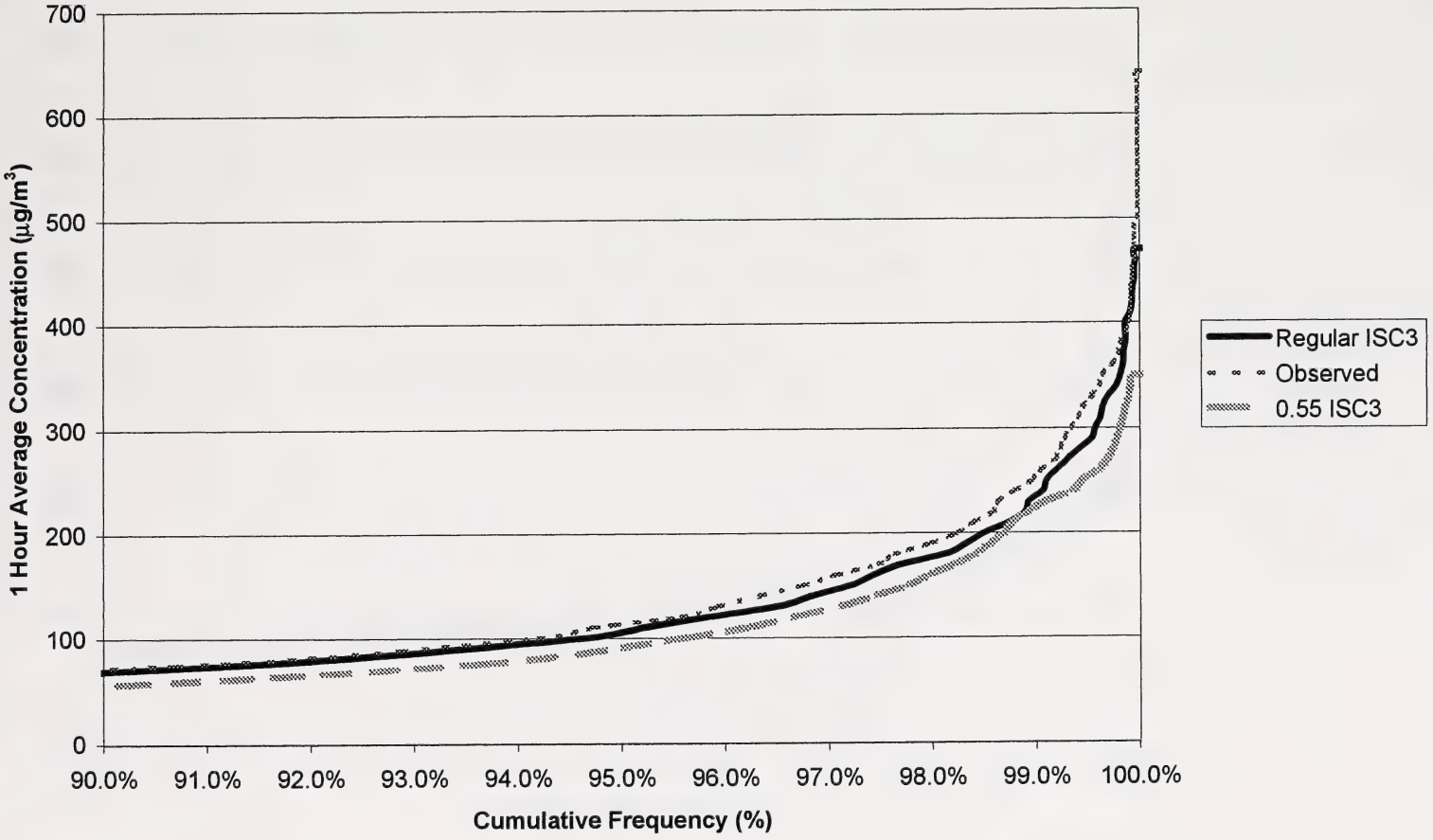


Figure B3: Cumulative Frequency of Predictions and Observations for the Redwater Trailer #14-36, Fort Saskatchewan

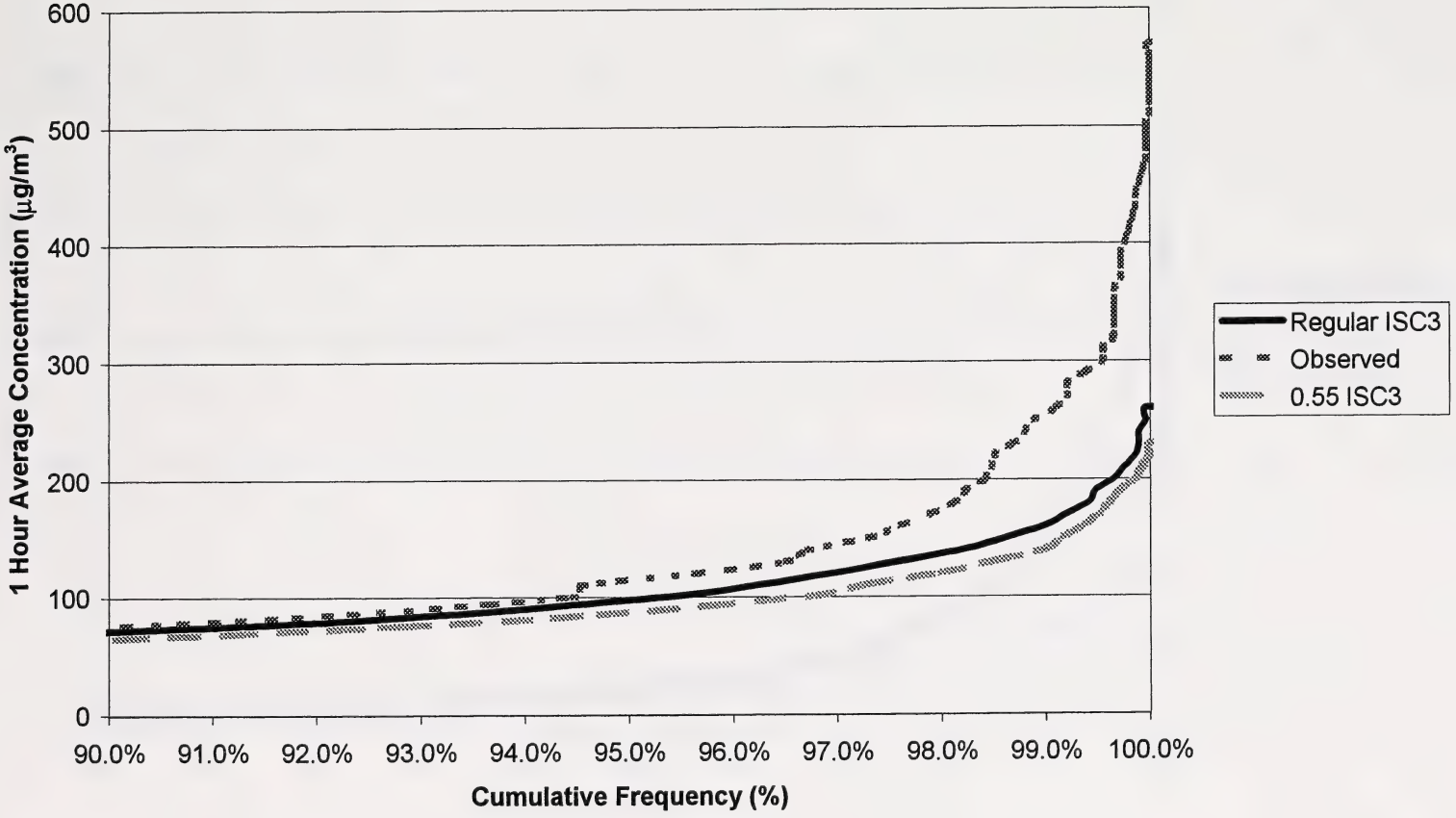


Figure B4: Cumulative Frequency of Predictions and Observations for the Imperial Oil Monitor, Fort Saskatchewan

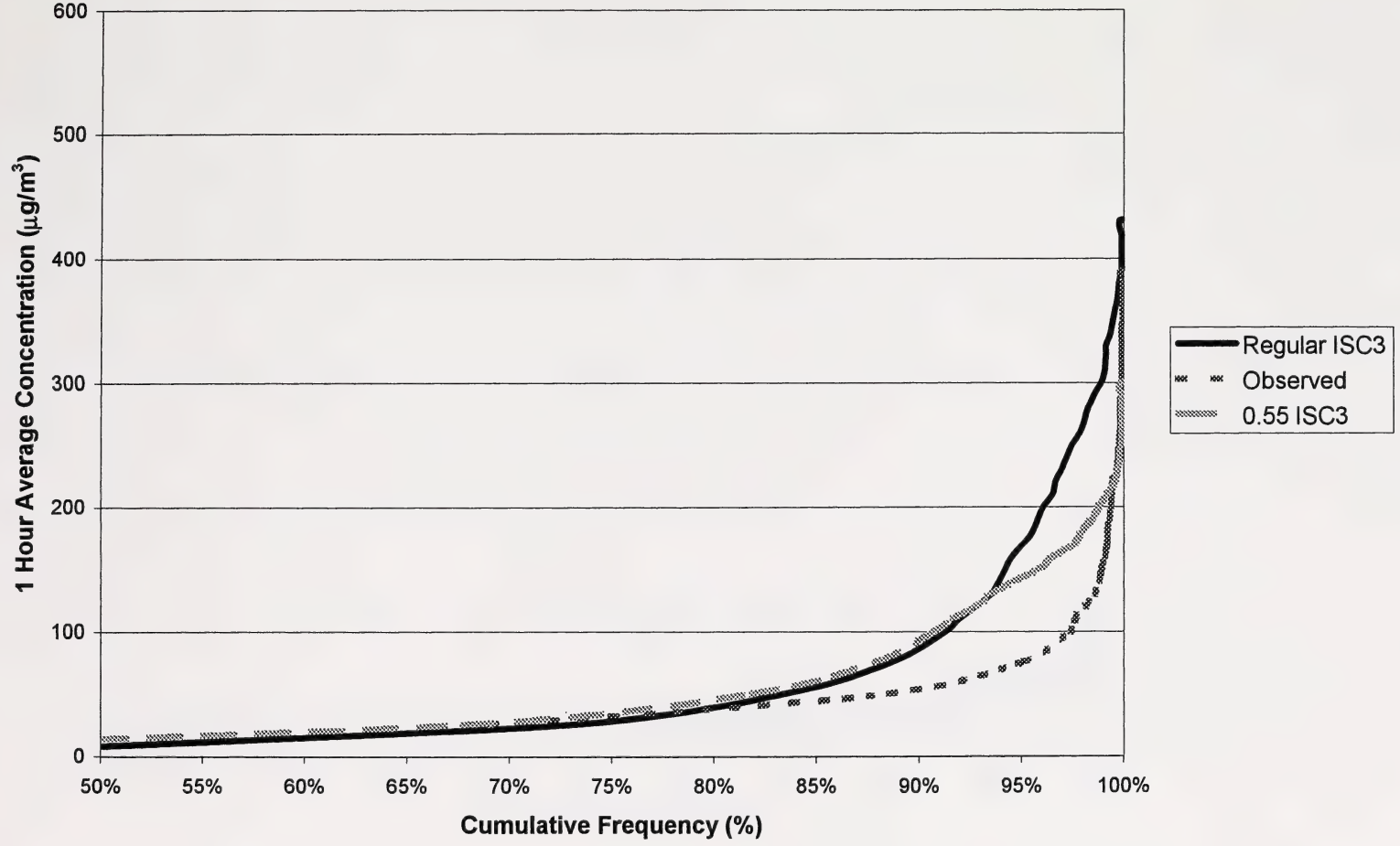


Figure B5: Cumulative Frequency of Predictions and Observations for Balzac Trailer #2

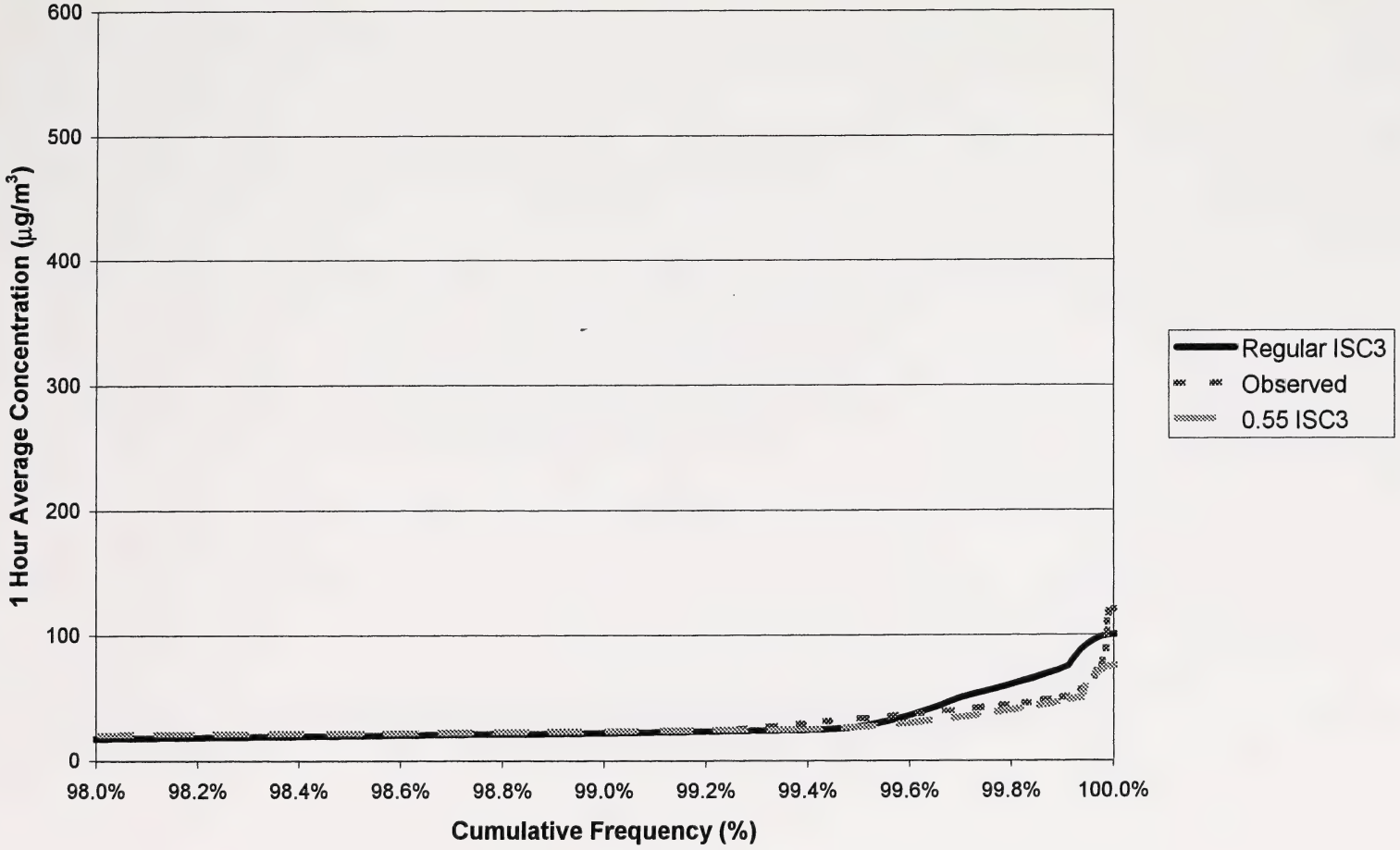


Figure B6: Cumulative Frequency of Predictions and Observations for Balzac Trailer #3

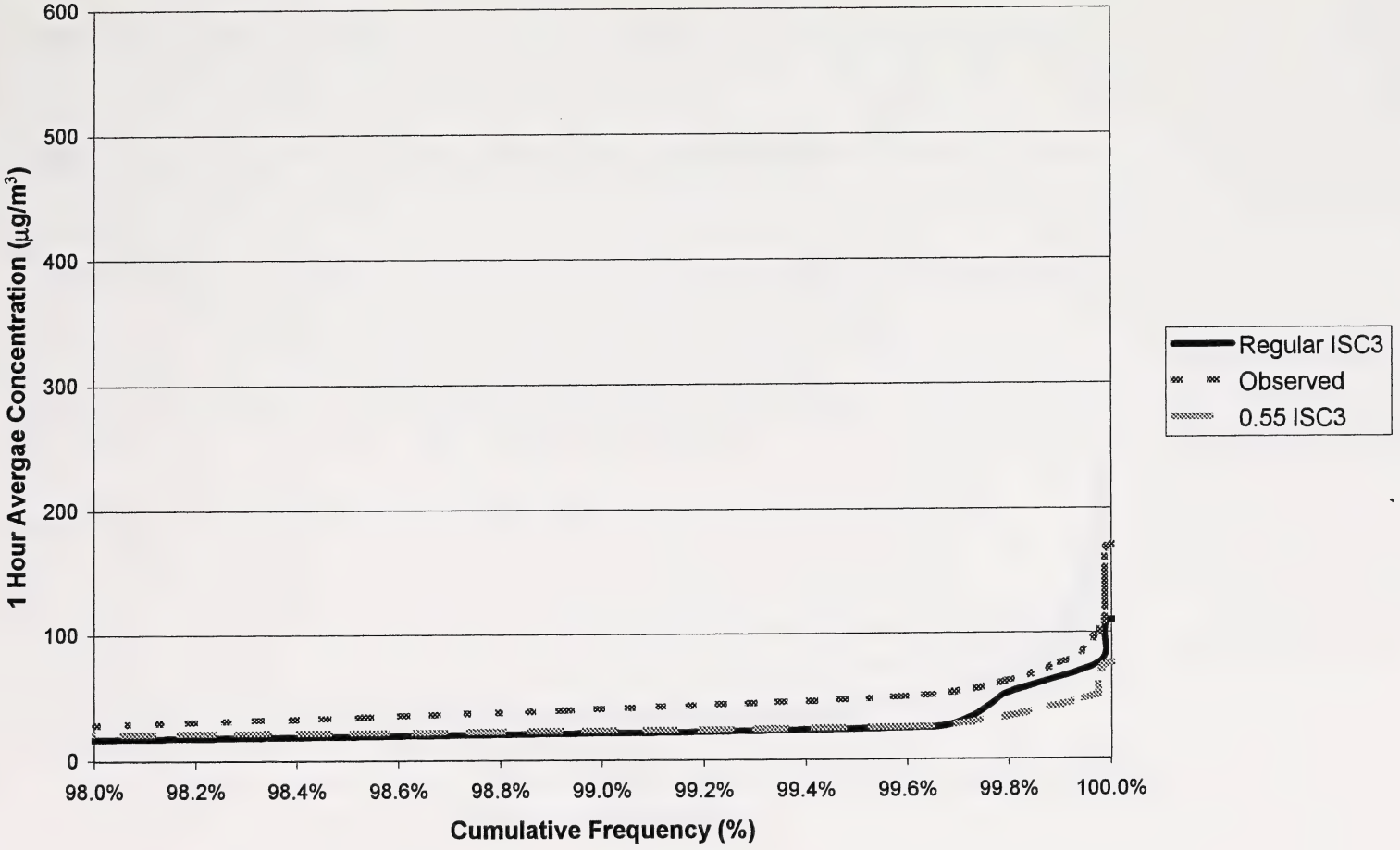


Figure B7: Cumulative Frequency of Predictions and Observations for the Bonertz Monitor, Waterton

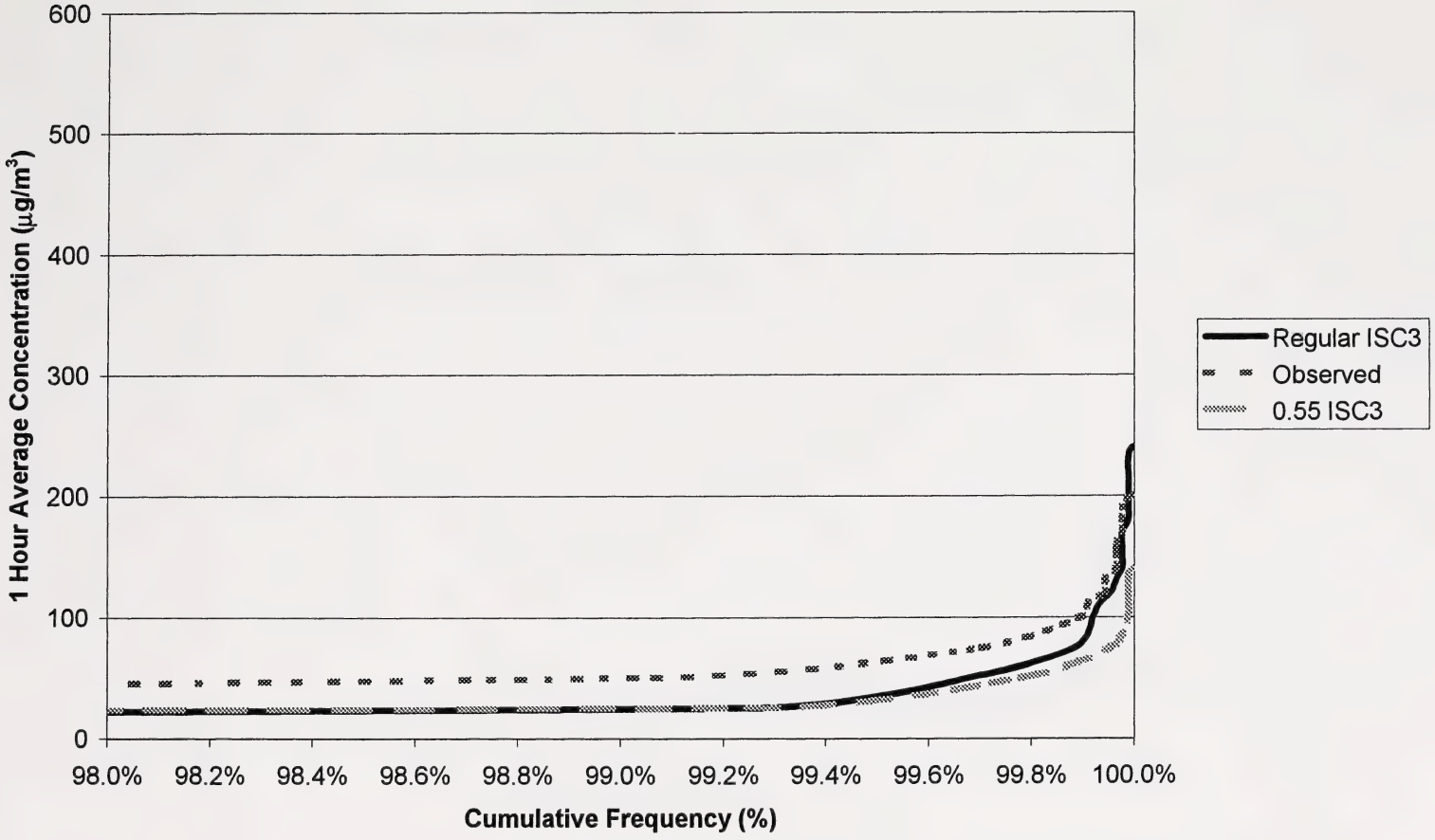


Figure B8: Cumulative Frequency of Predictions and Observations for the Carpentier Monitor, Waterton

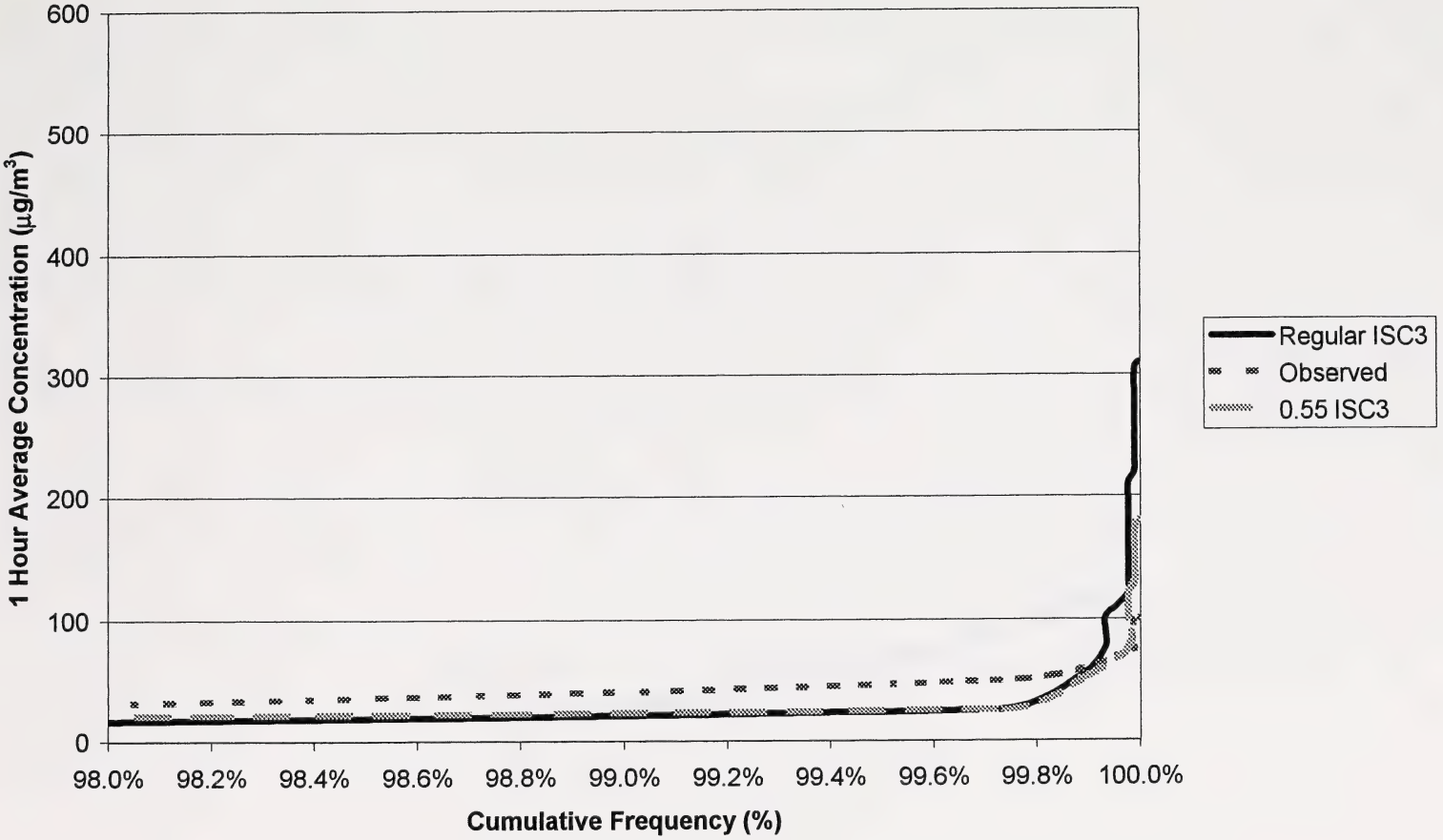


Figure B9: Cumulative Frequency of Predictions and Observations for the McRae Monitor, Waterton

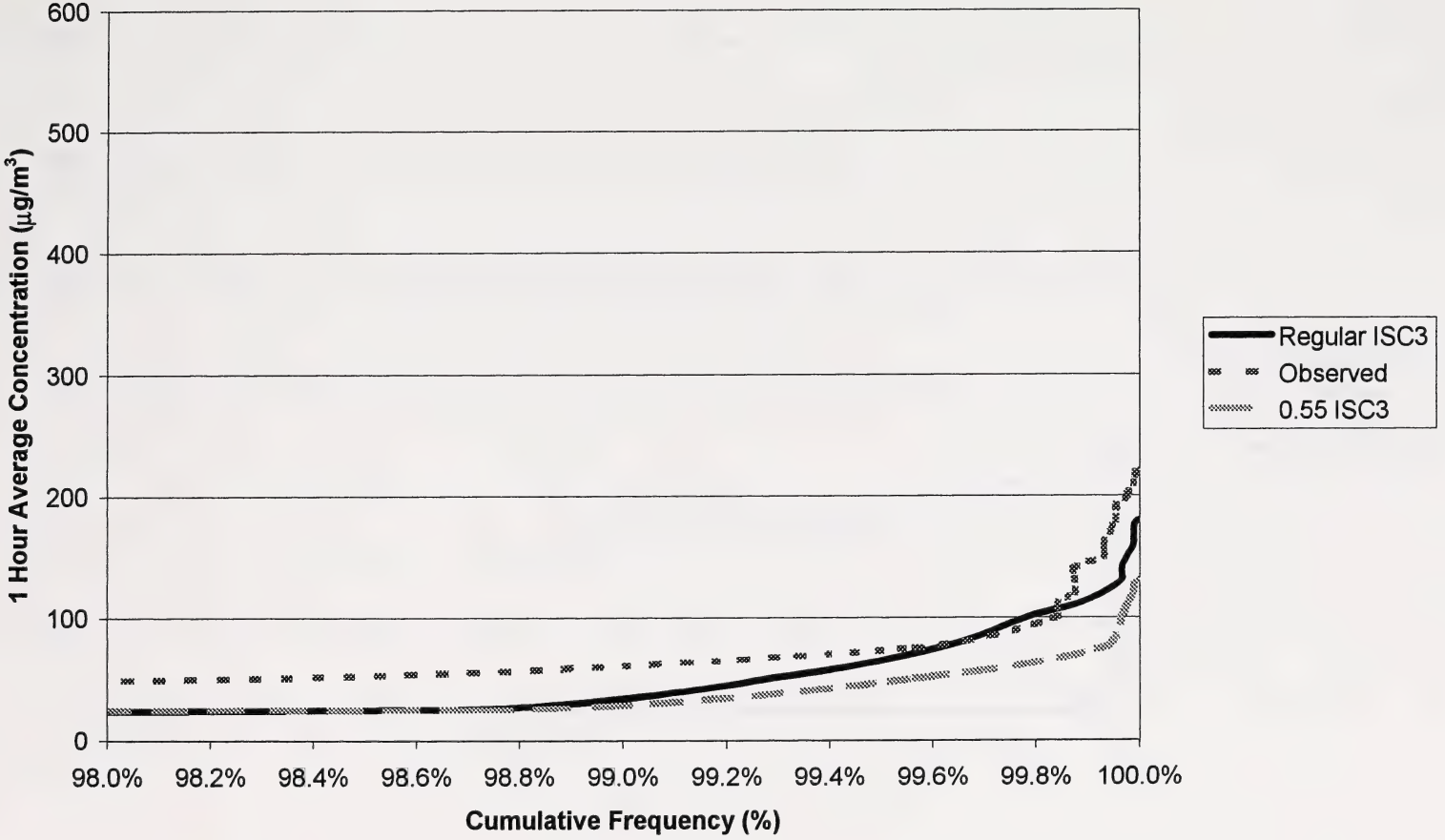


Figure B10: Cumulative Frequency of Predictions and Observations for the Riviere Monitor, Waterton

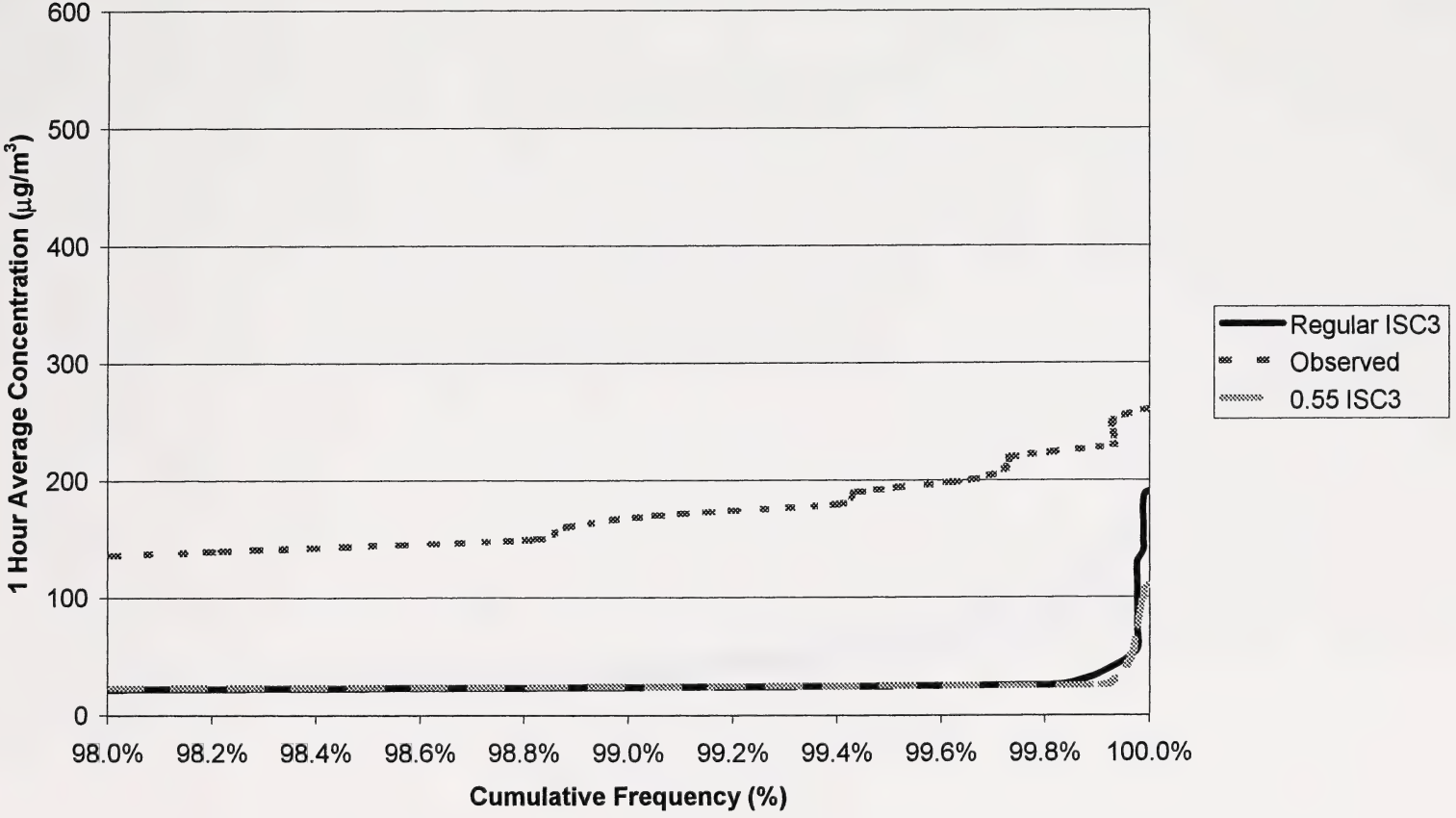


Figure B11: Cumulative Frequency of Predictions and Observations for the Burns Monitor, Waterton

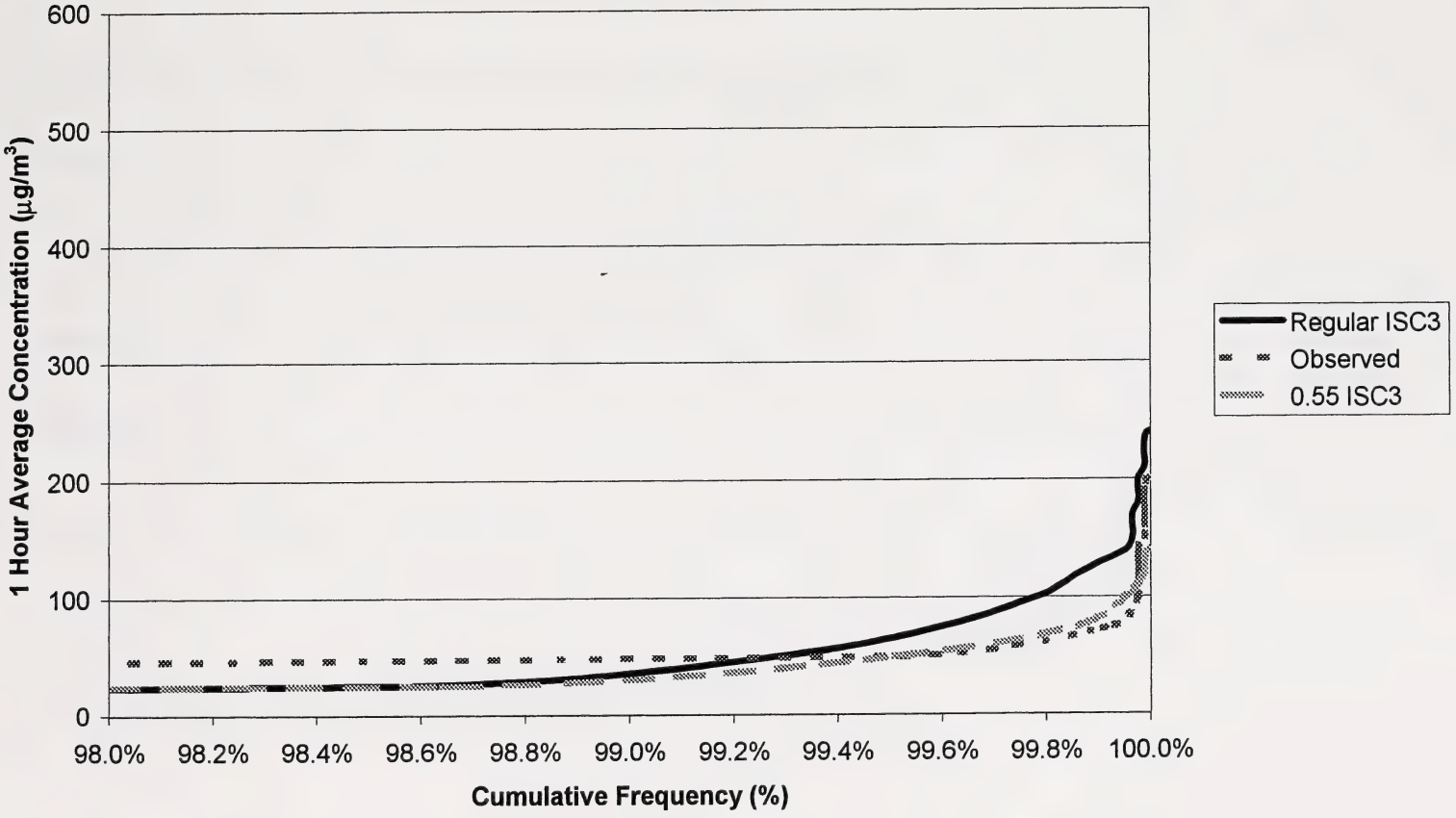


Figure B12: Cumulative Frequency of Predictions and Observations for the Lower Camp Trailer, Oil Sands

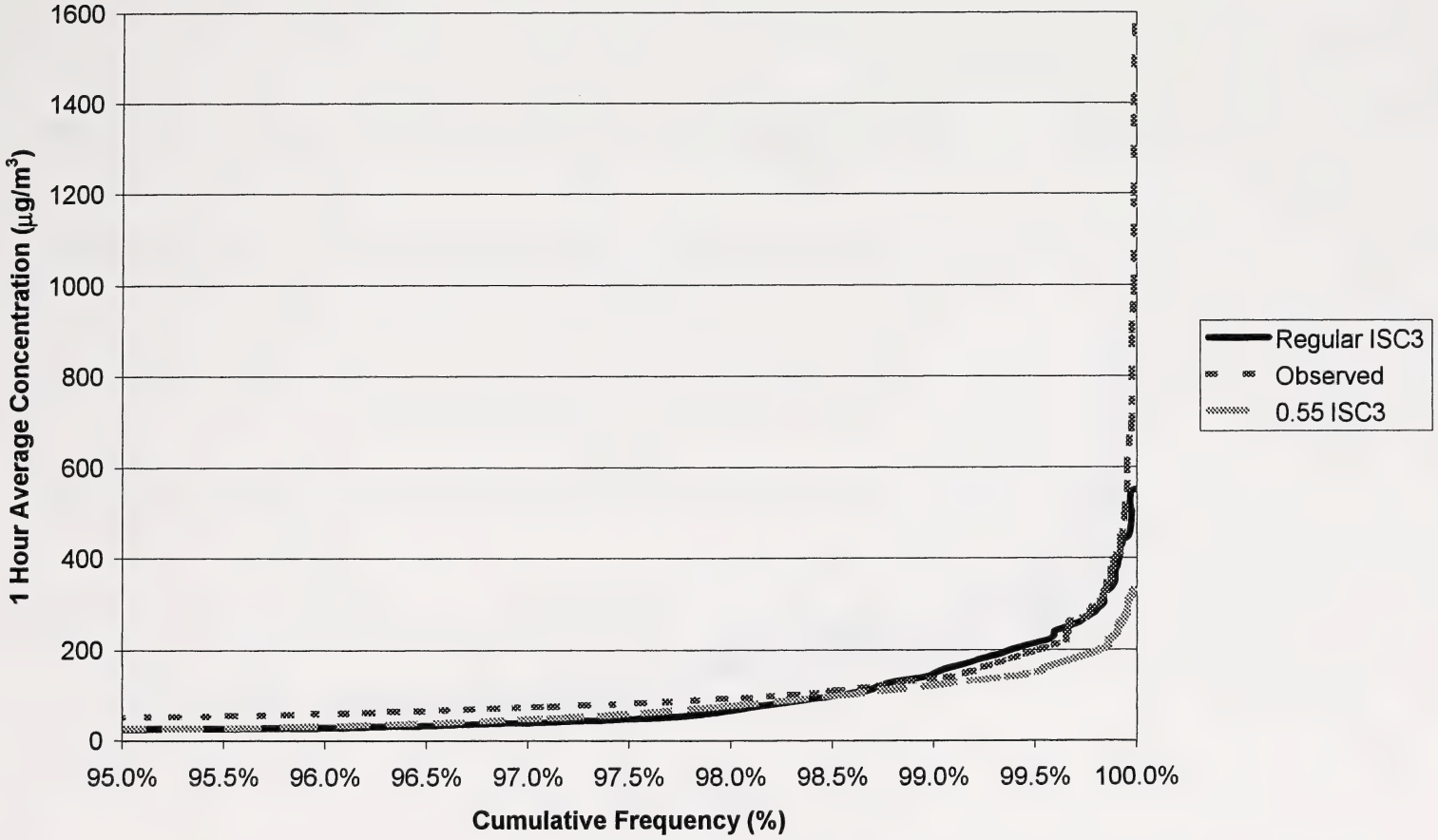


Figure B13: Cumulative Frequency of Predictions and Observations for the Poplar Creek Trailer, Oil Sands

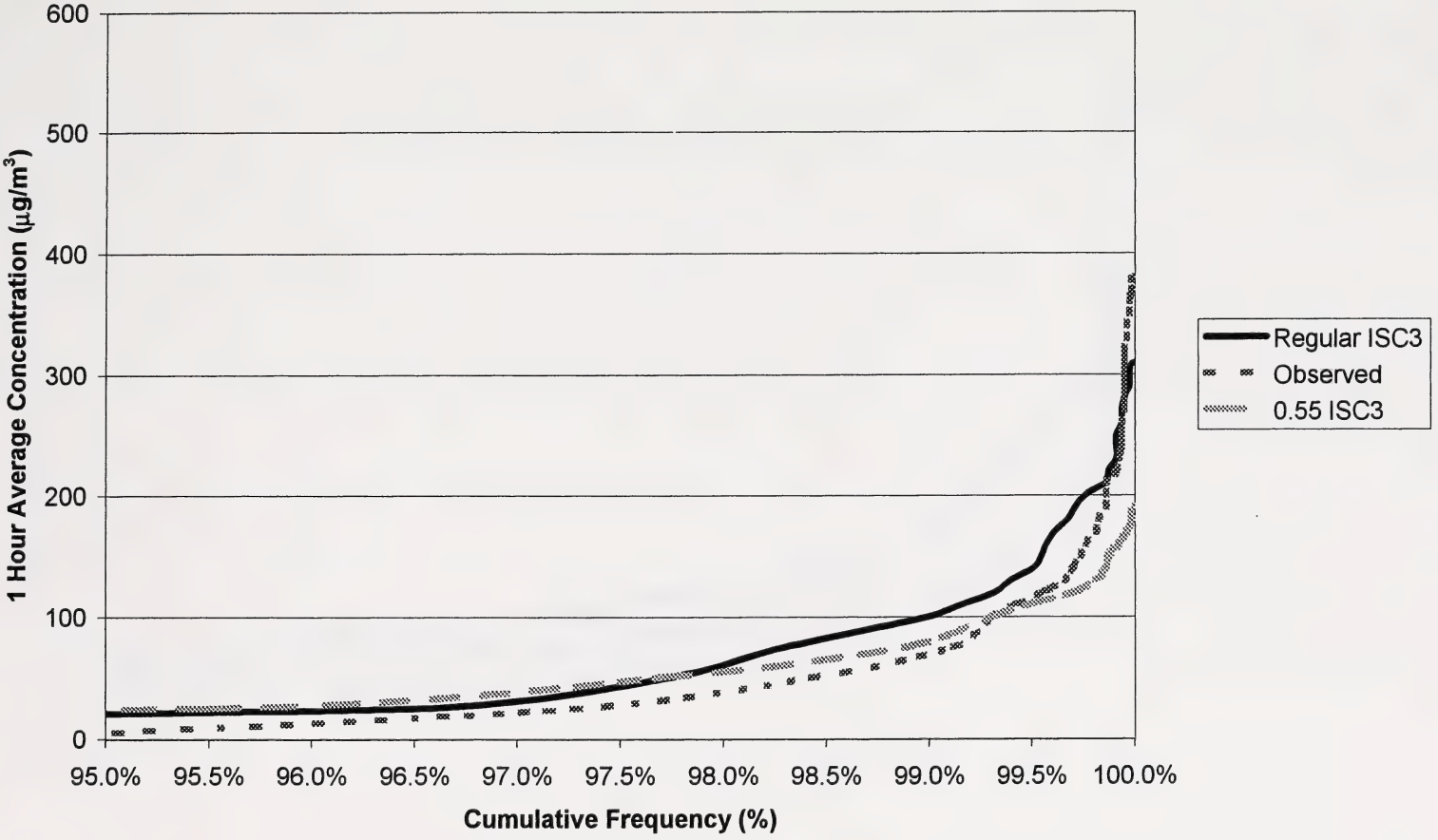


Figure B14: Cumulative Frequency of Predictions and Observations for the Athabasca Bridge Trailer, Oil Sands

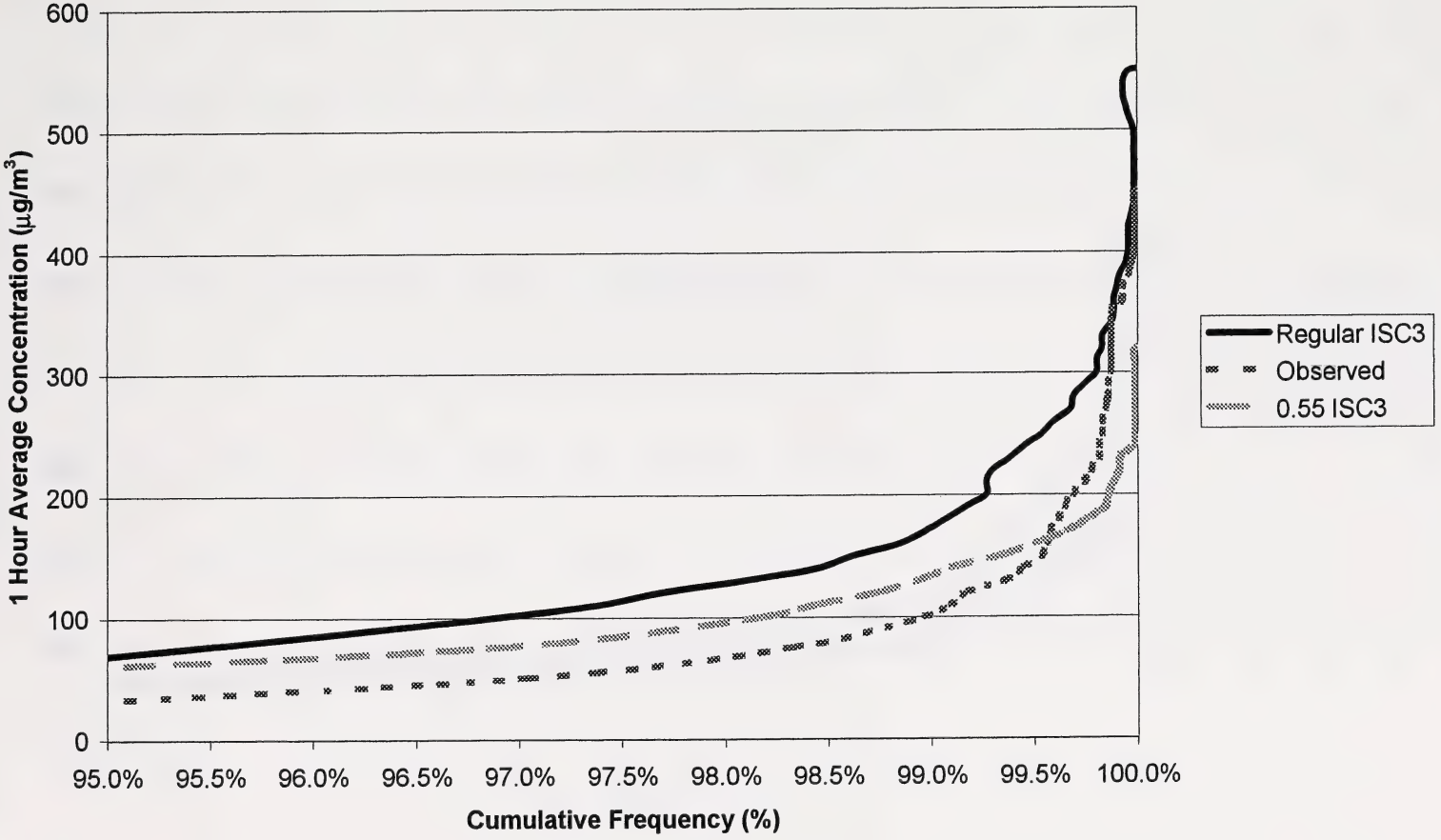


Figure B15: Cumulative Frequency of Predictions and Observations for the AQS4 Trailer, Oil Sands

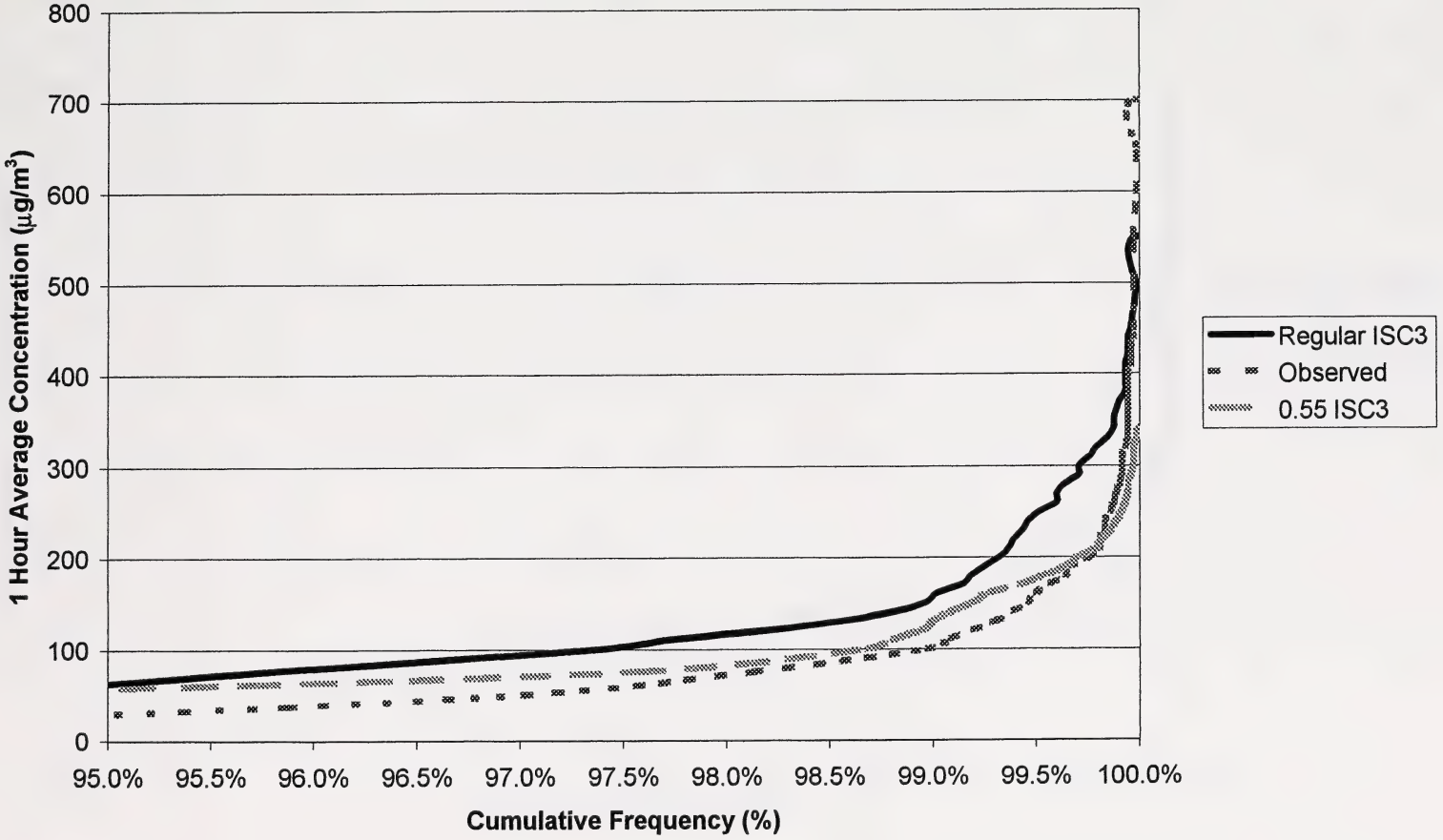


Figure B16: Cumulative Frequency of Predictions and Observations for the AQS5 Trailer, Oil Sands

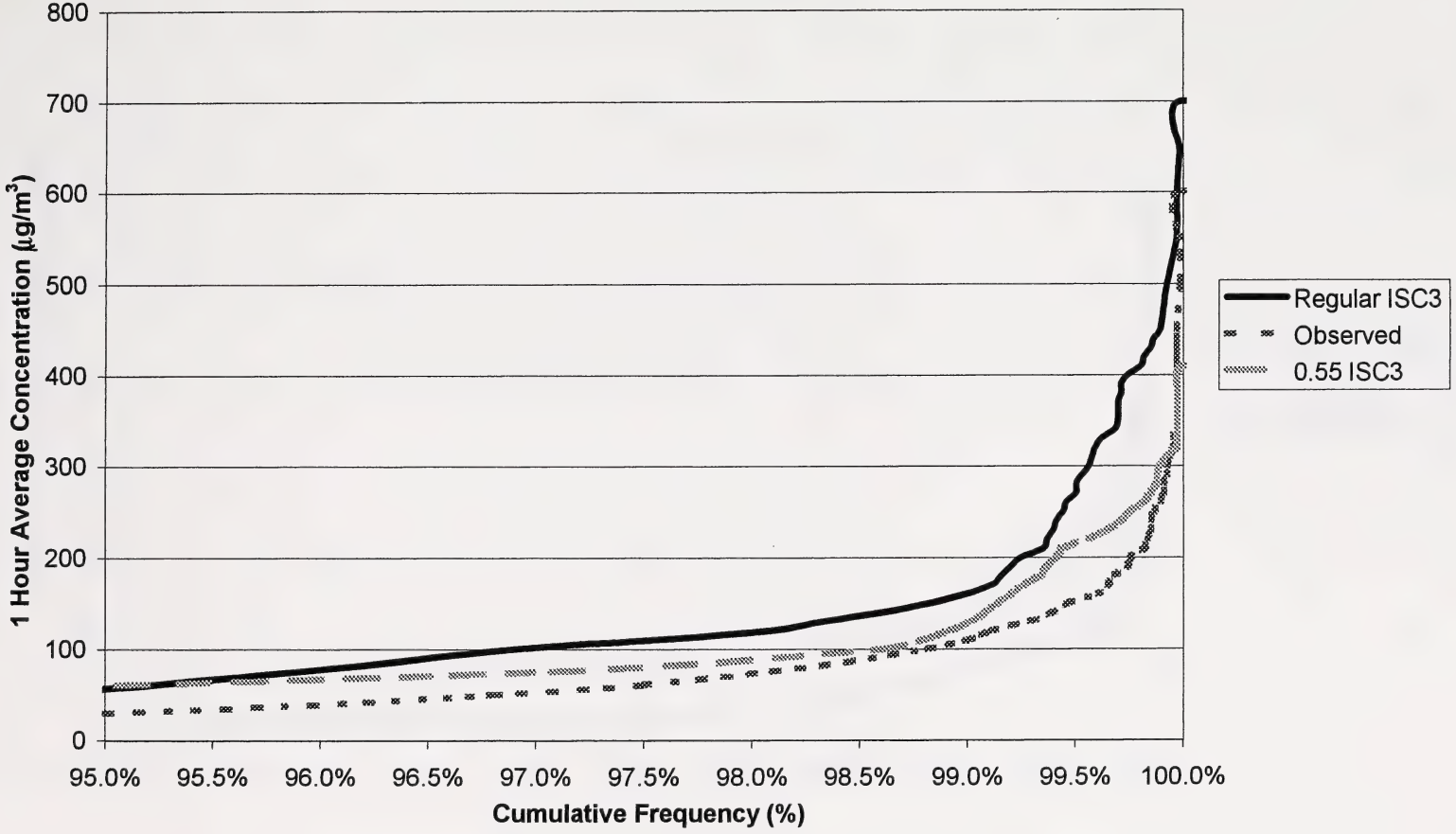


Figure B17: Cumulative Frequency of Predictions and Observations for the Fort McMurray Trailer, Oil Sands

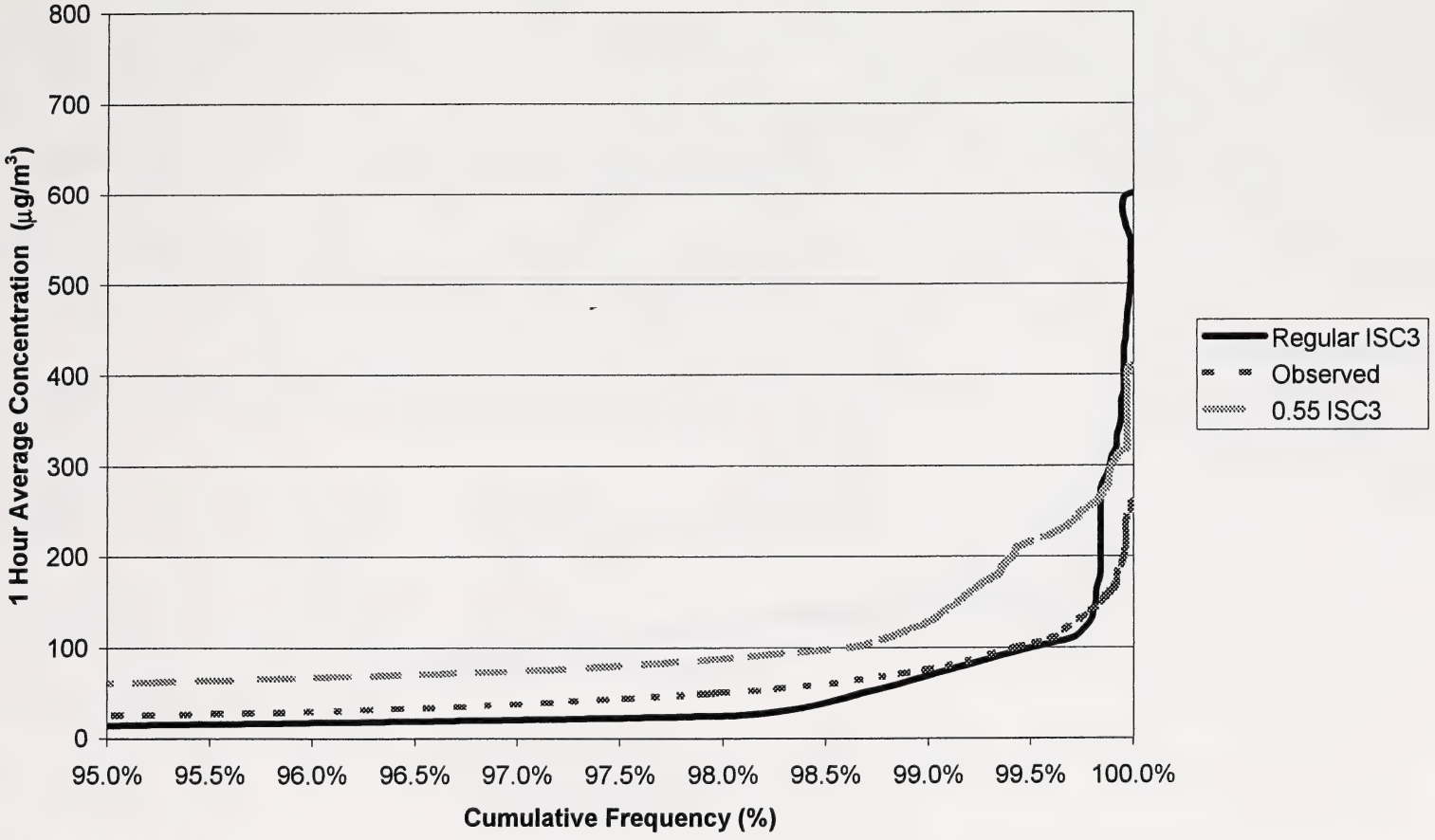
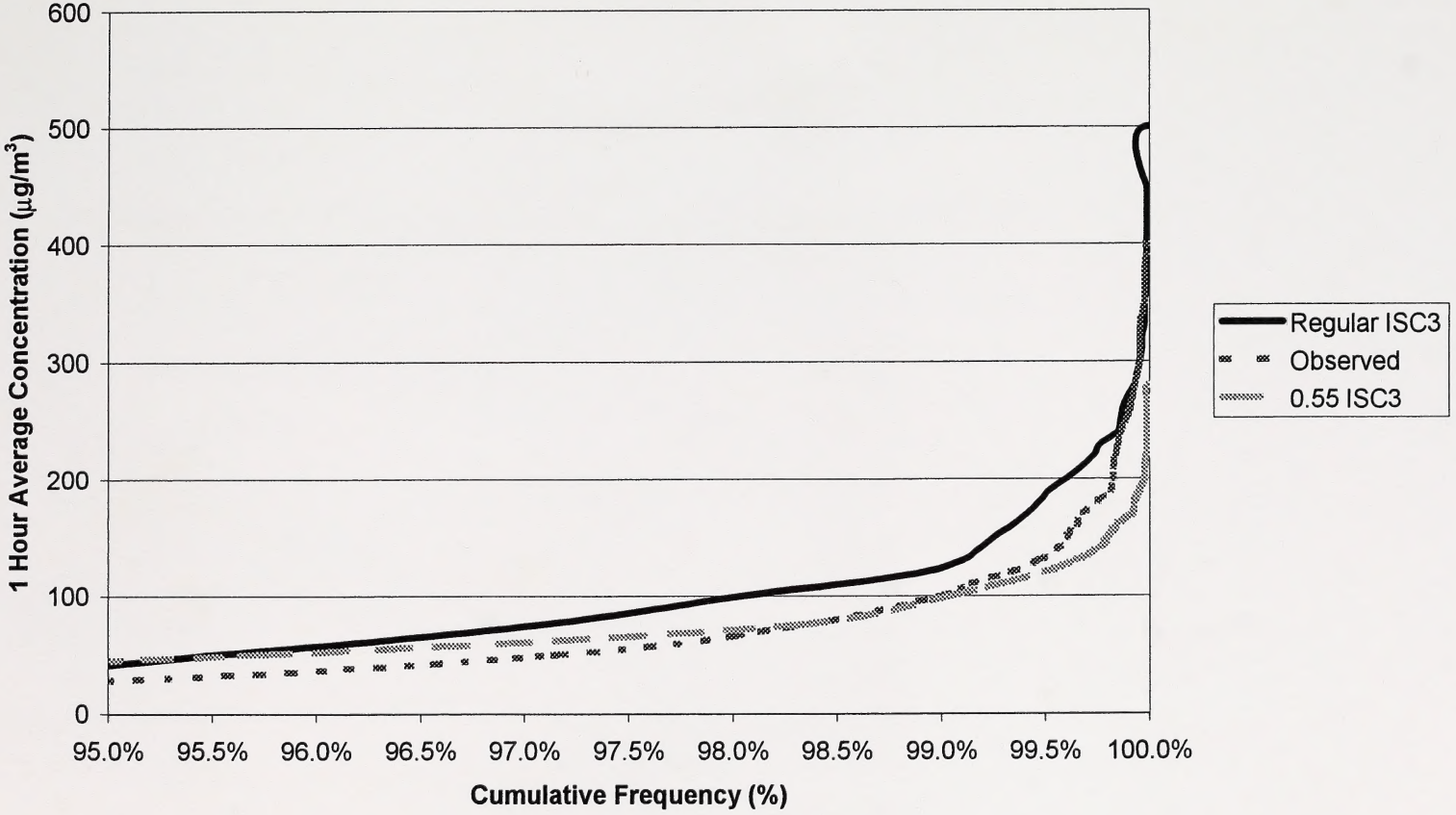


Figure B18: Cumulative Frequency of Predictions and Observations for the Fort McKay Trailer, Oil Sands



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